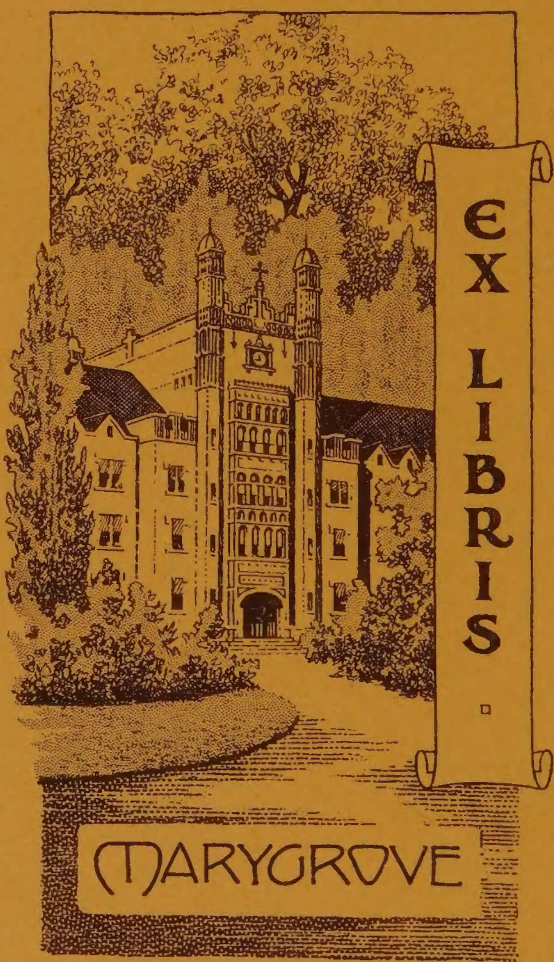
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A HANDBOOK OF PHOTOGRAPHY IN COLORS.

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SECTION I.

BY THOMAS BOLAS.

HISTORICAL DEVELOPMENT OF HELIOCHROMY — GENERAL SURVEY OF PROCESSES — DIRECT HELIOCHROMES ON SILVER CHLORIDE.

SECTION II.

BY ALEXANDER A. K. TALLENT.

TRI-COLOR PHOTOGRAPHY.

SECTION III.

BY EDGAR SENIOR.

LIPPMANN'S PROCESS OF INTERFERENCE HELIOCHROMY.

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PREFACE TO FIRST AMERICAN EDITION.

THE importance of the subject matter treated in the following pages, and the completeness with which the English editors have treated it, warrant us, we believe, in presenting it to the American public as a standard reference book on the subject of photography in colors, and one which, we hope, may be the means of bringing its problems nearer to complete solution.

E. & H. T. ANTHONY & CO.

NEW YORK, June, 1900.

THIRTY-ONE years ago the firm of Marion published the Pioneer Work on Photography in Colors (Les Couleurs en Photographie, par Louis Ducos du Hauron, Paris, 1869, A. Marion), a work containing the basis of practically all phases of the Trichromatic Photography of the present day. This work, however, appeared before the time was ripe for the Process. In now presenting the Public with the present Volume we feel satisfaction in following a line we opened up over a quarter of a century ago; but there is this difference—Photography in colors is now an industrial fact.

MARION & CO.

A HANDBOOK OF PHOTOGRAPHY IN COLORS.

SECTION I.—By THOMAS BOLAS.

Historical Development of Heliochromy. General Survey of Processes. Direct Heliochromes on Silver Chloride.

CHAPTER I.

THE ORIGIN AND DEVELOPMENT OF HELIOCHROMY.

Ritter — Seebeck — Wollaston — Niepce I — Herschel — Hunt — Becquerel—Niepce II—Beauregard—Ducos du Hauron— —Zenker—The more recent workers in relation to Theory and Practice.

Heliochromy, the art of producing heliochromes, or photographs in colors, more or less exactly corresponding to those of the original objects was experimented with and carried out, in a fashion, some years before camera pictures were made in the ordinary sense of the term. Before the beginning of the nineteenth century it was well known that light would chemically alter and darken certain substances, notably chloride of silver, and in the first year of the nineteenth century (1801) Herr Ritter, of Jena, noticed that the various rays of the spectrum differ considerably in their action upon chloride of silver.

The Work of Seebeck.

T. J. Seebeck, who, like Ritter, lived at Jena, repeated Ritter's experiments, and he traced some more or less constant relations between the spectral color and the tint assumed by the silver chloride, and in 1810 he obtained a reproduction of the spectrum, in some approach to the natural colors, upon paper impregnated with chloride of silver. These heliochromic images were, however, unfixed. The celebrated poet, dramatist, and philosopher, Goethe, took great interest in the work of Seebeck, and the best account of the experiments in question is preserved in Goethe's treatise on color. Seebeck says that when he projected a solar spectrum upon paper prepared with moist chloride of silver, and the action was allowed to continue for a quarter of an hour or a little longer, the following results were observed: In the violet band of the spectrum the chloride generally became reddish-brown, but sometimes tending to violet. This coloring extends all through and a little beyond the violet. In the blue part of the spectrum the chloride of silver becomes clear blue; the tint becoming fainter in the green. In the yellow no action took place, or only a faint yellow tint was produced; but in the red and the ultra red a rose or lilac coloration resulted.

Wollaston's Experiments.

About the same time as Ritter and Seebeck made the above observations Wollaston, in England, studied the effect of the spectrum, not only on chloride of silver, but also on an organic substance, gum guaiacum; this material being dissolved in alcohol and white card was washed over with the solution. An interesting record of these experiments is to be found in Brewster's Optics, 1831 edition, page 91; a work published before photography, as we understand it, was known. Wollaston concentrated the various spectral rays on his card prepared with guaiacum, a lens being used for this purpose. In the violet and blue rays it acquired a green color; in the yellow no effect was observed. Pieces of prepared card which had become green in the violet or blue rays were restored to their original tint by exposure to the red rays. In an atmosphere of carbonic acid the violet and blue rays did not make the prepared card green; but the restoration of the original tint by the red rays took place in an atmosphere of carbonic acid. Heat also was found to destroy the green color.

Remarkable Observations by Niepce I.

It is now generally known that J. Nicephore Niepce obtained fixed pictures in the camera at least twelve years before the first publication of the details of a photographic process, and in a document given by Niepce to Daguerre at the time of a partnership being entered into by the two investigators there is a passage which shows how near Niepce was to the direct heliochromic method by interference, commonly called the Lippmann method. The document in question is dated December 5th, 1829, and was published by the order of the French Government when the Daguerreotype process was made public. Niepce details the results obtained by exposing in the camera glass plates and silvered copper plates coated with a thin film of bitumen, and in speaking of a landscape thus obtained (apparently on glass), he says: "If this landscape be viewed by reflection in a mirror, on the varnished side, and at a certain angle, the effect is striking, while by transmission it only presents confused and shapeless imagery; but what is really surprising, in this position the mimic tracery seems to affect the local colors of certain objects. In reflecting on this remarkable fact, I have sometimes thought that consequences might be deduced connected with Newton's theory of colored rings. . . . The circumstance appears to me sufficiently interesting to excite new researches, and to merit more profound inquiry."

Sir John Herschel's Work.

In the year 1839 Sir John Herschel published the first of an important series of papers on various photographic processes. A

paper published in 1840 (Philosophical Transactions) deals with the colored image of the spectrum (showing red, green, and blue) obtained on chloride of silver paper; he discusses the question of producing photographs in natural colors.

Work of Hunt, Becquerel, and the Second Niepce.

These investigators, who worked and wrote from 1844 to 1867, did but little for progress except that Becquerel gave precise directions for chlorinating copper plates for heliochromic effect. The work of Niepce II. is also valuable from the point of view of precise directions. Detailed instructions for obtaining the Seebeck effect will be found in Chapter II. The experiments of Wiener, there detailed, show that Becquerel's results on silvered copper plates are partly due to interference, or the Lippmann effect, as it is commonly called (see page 6).

Testud de Beauregard.

At meetings of the Photographic Society of France held during the years 1855 and 1856, Testud de Beauregard put forward the view that a silver photograph which appears to be either without color, or having such very slight tints of color as only to be doubtfully recognized as colored, may possess a selective power or a potentiality for color. Such views have been repeatedly put forward since, and in another place (page 15) they are considered in relation to Wiener's theory of the Seebeck effect, also the difference between natural colors and spectrum colors.

The work of Louis Ducos du Hauron, commencing in 1859.

In 1869 the first hand-book of practical Heliochromy was published in Paris by A. Marion, 16 Cité Bergère, the author being Louis Ducos du Hauron, who, about ten years before, had foreshadowed this and the cinematographe in a paper on visual sensations read before the *Société des Arts et Sciences d'Agen* on January 20, 1859. Other and fuller publications took place in 1862, the photographic reconstitution of colors being clearly defined. Louis Ducos du Hauron's first hand-book of Heliochromy contains all essentials for success with the three-color process, not only by superposition of colored images (see page 40), but also by the colored line system which has recently been elaborated by Joly and others (see pages 49 and 51). The exact title of the book is *Les Couleurs en Photographie: Solution du Problème*, and it consists of fifty-eight octavo pages. Like many epoch marking books, it was scarcely noticed when published. Another book—practically a second edition of the above (108 pages) was published in 1878 by Louis, in conjunction with his brother Alcide, and a much larger work (488 pages) in 1897 by Alcide alone; both these latter being published by Gauthier-Villars, of Paris.

Suggestions by Clerk-Maxwell, H. Collen, and Charles Cros.

Lecturing at the Royal Institution in 1861 Clerk-Maxwell indicated the possibility of three-color heliochromy, and writing to the *British Journal of Photography* in 1866, H. Collen made a suggestion in the same direction, but on an incorrect color basis for taking the necessary negatives. Charles Cros in 1867 applied for a French patent on the same erroneous basis as that involved in Collen's suggestion. The above proposals appear to have been made without knowledge of the earlier work of Louis Ducos du Hauron.

Zenker, Carey Lea, Wiener, Ives, Lippmann, and the more recent workers.

Dr. Wilhelm Zenker, of Berlin, published, in 1868, a work on heliochromy which was rather theoretical and speculative than practical in the ordinary acceptation of the term. In this work he so distinctly foreshadows the modern Lippmann process (see pages 27 and 28) that the method itself might not unreasonably be called the Zenker method, or the Zenker-Lippmann method; this remark, however, involves not the smallest shadow of reproach to M. Lippmann, as this gentleman in writing his original memoir on interference heliochromy, gave full credit to Dr. Zenker for his early work and suggestions. The next very important step in progress after the work of Zenker was made by Carey Lea, who, in 1887, obtained colored haloid salts of silver by chemical means (see page 13), and in studying the action of colored light on these and noting in many cases the reproduction of the incident color he expressed a rather confident opinion that his results would lead to the reproduction of natural colors. After this period we find so many active workers that it becomes convenient to close this historical sketch with a short mention of the work of a few, reserving all detail for consideration in future chapters. Herr Otto Wiener's two Memoirs contained in *Wiedemann's Annalen der Chemie und Physik* (1st Vol. of 1890, p. 203, and 2d Vol. for 1895, p. 225) afford important contributions to the theory of the Zenker and Seebeck effects (see pages 9 and 27). The patient labors of Mr. Fred E. Ives, not only in explaining the theory of three-color heliochromy, but also in bringing about its practical realization (page 41), are well known; while Professor Lippmann's name is known even to the newspaper reader in connection with interference heliochromy. Professor Joly has done very much in practically realizing a three-color method, in which colored dots or lines in tints corresponding to the three-color sensations (page 49) are made to coalesce and give much the same kind of effect as is obtained by ordinary three-color heliochromy; a method indicated by Louis Ducos du Hauron as far back as 1862 and fully explained in his work published by A. Marion at Paris in 1869.

Dialytic System of Ducos du Hauron and Semi-dialytic System of Bennetto.

To place three sensitive surfaces one behind the other like the leaves of a book and to make one exposure in an ordinary camera may still appear an impracticable dream. Ducos du Hauron has recently indicated such a method; and, although he appears to recognize that at present it is far from perfect, he predicts that this system—which he calls the dialytic system—will in the end supersede all three-color systems involving the optical complication incident to several lenses or several reflectors. Furthermore, M. Bennetto has devised a semi-dialytic system in which one lens and one reflector are used and in which the size of the camera need not exceed that of an ordinary camera, one plate being in a dark slide, placed in the ordinary position; while a single reflector diverts a portion of the light to one side or top of the camera, where is a slide containing two sensitive surfaces superimposed.

In carrying out M. Ducos du Hauron's dialytic system, a non-orthochromatic plate is next the lens, but the film must be highly transparent, practically colorless, and of very low sensitiveness; moreover, the back of the plate must be turned towards the lens. This plate is acted on mainly by the blue and violet rays, and it gives a printing surface for the impression in yellow. As this outside non-orthochromatic plate is practically colorless and transparent, the light passing through it is almost normal both as regards quality and intensity, while the low sensitiveness of this outer plate allows of a long exposure of the under surfaces. Next underneath is placed a thin transparent yellow pellicle which cuts out the blue, and under this pellicle is a film specially sensitive to the green. Next in order comes a red pellicle, and under this a plate (film towards the lens), which is specially sensitive to the red and orange. Obviously by a suitable selection of sensitive surfaces and colored screens a system of color selection not very widely differing from that indicated by theory would be possible, although with the coloring materials and sensitive surfaces now known to be available, theoretical perfection is not realizable, chiefly by reason of the necessity for allowing all the red rays to pass through the surface which is to be impressed by the green, and the long exposure required for the "red" plate. A suggestion of Ducos du Hauron is to manufacture a complete, or quintuple, set of elements for use in an ordinary dark slide, and this quintuple film (three sensitive surfaces and two color screens). This set he calls *polyfolium chromodialytique.* At any time new researches in the color sensitising of emulsions may bring the purely dialytic method into prominence, but meanwhile the semi-dialytic method of Bennetto, mentioned above, merits special attention. His camera contains a single red glass reflector set at an angle of forty-five degrees with the axis of the lens. Opposite the lens is the red-sensation plate, while the rays for the

blue-sensation plate and the green-sensation plate are reflected to the top or side of the camera where there is a second dark slide in which a very transparent plate of low sensitiveness with the glass side towards the lens is outwards, then a yellowish green film-screen, and behind this is a special plate to record the green sensation.

Suggestions as to Diffraction Heliochromy.

Professor R. W. Wood points out that if we take three diffraction gratings, spaced so that the deviation of the red of one corresponds to that of the green of the second and to the blue of the third, a viewing lens can be so placed in relation to them that to the eye the colors overlap and the sensation of white results. Cutting out any grating will then be equivalent to cutting out the corresponding color. Hence it becomes possible to print the three positions of the heliochromic triplet in suitable line or grating systems, to superimpose these grating prints, and to obtain heliochromic effects by illuminating from behind with a long narrow source of light. Wood's grating prints are composites of photograph and grating made on bichromated gelatine, but Mr. P. E. B. Jourdain suggests the possibility of producing a grating heliochrome directly in the camera. He says: "If a colored image is formed by a lens on a plate, and a grating is interposed a short distance in front of the plate, the image will be split up into minute bands corresponding to the wave length at any point. In fact, new gratings where 'rulings' correspond to the colors at the various points of the picture would apparently be formed."

CHAPTER II.

DIRECT PIGMENTARY HELIOCHROMY, OR THE SEEBECK EFFECT AND ITS OUTCOME.

The Researches of Wiener—Photosalts of Carey Lea—Methods and Observations of Various Workers—Pigmentary Heliochromy in Practice.

THE first few items in the historical sketch may be taken as forming the introductory portion of the present chapter, and as a sufficient preparation for an understanding of

Wiener's Researches on the Seebeck Effect.

The first series of these researches, very briefly mentioned in the chapter of Historical notes (see page 6), was published a few months before the appearance of Lippmann's celebrated communication to the French Academy of Sciences, in which he signalized the actual realization of interference heliochromy. In this first paper Wiener shows that stationary or standing waves may bring about a laminated structure in a photographic film (see also page 25). The second paper, which was published after the classic memoir of Lippmann, appears to have been undertaken mainly with the view of ascertaining whether the colors obtained by all the various direct heliochromic methods depend wholly or partially upon interference of light, as caused by a laminated structure like that of mother of pearl. Two criteria of an interference heliochrome were postulated by Wiener. In the first place the color must vary with the angle at which the heliochrome is viewed, and in the second place the color by transmission must be complementary to that by reflection. Direct heliochromes of the spectrum were now made, in the first place by the method of Seebeck upon flocculent chloride of silver which had been previously somewhat darkened by the action of light, and in the second place upon a silver surface slightly chlorinated by the electrolytic method as recommended by Becquerel (see page 19), and in the third place upon paper prepared with chloride of silver and darkened by exposure to light. In order to examine the spectrum colors as impressed on these surfaces the following device was contrived, which allows the simultaneous viewing of a band of color under light at two angles of incidence; if the two portions of the band

show the same tint the color must be pigmentary in its nature; if, on the other hand, they show different tints the color must be partially or wholly due to interference.

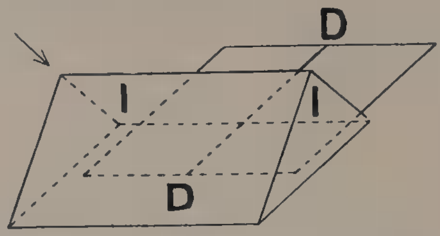

Fig. 1.

Let Fig. 1 represent a right-angled prism of highly refractive glass (1.75 for the line D), which is laid as shown upon the heliochrome of the spectrum. The observer looks in the direction indicated by the arrow, and let DD be the band of color obtained by exposure in the middle of the yellow. On viewing the band of color partly without the prism and partly through the prism (means hereafter mentioned being adopted to fill up the air layer and thus obviate total reflection), that portion of the yellow band seen through the prism will appear green or greenish if the color of the heliochrome is wholly or partially due to interference. If, on the other hand, the color is wholly pigmentary the color of that part of the band seen through the prism will appear identical with that of the portion of the band seen directly by the eye. Fig. 2, showing the end of the prism in section, will perhaps give a better idea of the arrangement.

To eliminate total reflection from the hypotenuse of the right-angled prism a drop of benzine must be allowed to flow between the glass and the heliochrome at the time of observation, and to allow of this in the case of a print on paper it is often convenient to turn up the uncovered portion of the print as shown by Fig. 2.

Fig. 2.

Heliochromes of the spectrum obtained upon flocculent silver chloride or upon paper prepared with silver chloride showed no change of tints when the bands of color were viewed partly through the prism as described above, but heliochromes obtained upon chlorinated silver surfaces always showed a change in tint. Thus a line drawn along the yellow band of the heliochrome would appear as if in the green when viewed by the prism, and a line drawn in the greenish blue appear as in the well defined blue. So far there was proof that in the case of the Seebeck effect on ordinary flocculent

silver chloride or on prepared paper the coloring material was pigmentary in its nature, and that when Becquerel's bright metallic basis was used the effect was—partially at least—due to interference by reason of a laminated structure like mother of pearl. A confirmation was obtained by transferring the Becquerel heliochrome from the metal to a sheet of gelatine, when it was found that the color by reflected light was not the same as the color by transmitted light, but the colors shown by transmitted light and by reflected light not being exactly complementary there was obviously some other source of color than the laminated structure. Thus it was shown that results obtained by Becquerel on metal plates are due partly to pigmentation, or the Seebeck effect, and partly to interference, or the Zenker-Lippmann effect. If the several colors had been entirely due to interference the color by transmitted light would have been exactly complementary to those by reflection; but not being exactly complementary, it is concluded that both interference and the pigmentary formation contributed to the result. When direct heliochromes by the Seebeck method on flocculent chloride of silver or from chloride on paper were examined first by reflection and then by transmission, no difference in color was observed. Hence they were concluded to be wholly due to the pigmentary or Seebeck effect.

The Ideal Chromo Sensitive Surface according to Wiener.

Wiener takes it as an experimental fact that a true chromo sensitive surface can exist, although not yet obtained in a perfect condition, and he proceeds to consider the conditions under which a single surface can be chromo-sensitive, or can take every tint of a colored image projected upon it. In theorizing as to the true nature of such a surface he was guided by some remarkable experiments which he made with the spectrum upon darkened chloride of silver. A spectrum having been impressed upon this paper, the heliochrome, or color photograph, was set at right angles to the spectrum so that the effect of several spectral colors on each tint of the heliochrome could be studied. The red illumination of the second exposure destroyed every tint but the red on the heliochrome. In a similar way the blue light of the spectrum destroyed all colors but the blue on the heliochrome. In the case of the yellow, however, the phenomenon of the destruction of all other tints (although indicated) was less definite. Setting out with the principle that in the case of a chromo-sensitive surface, each colored radiation will destroy all tints but its own, he concludes that the chromo-sensitive surface must be black and composed of at least three physical portions or elements. In the black state the chromo-sensitive surface must obviously be absorptive of all colors, and we will suppose that red light plays upon it. At first the red is completely absorbed, but in being absorbed it slowly destroys those physical portions or elements

which can absorb red, and obviously when these are fully destroyed the surface will no longer absorb red; in other words, it will be red. Let the black absorbent surface be now exposed to green light. As before the light will be absorbed, and it will slowly destroy those physical portions or elements which absorb it. When these elements —absorbent of green—are fully destroyed no more green will be absorbed, and the surface will be green. Now let us take a third supposition. The black absorbent film is exposed to blue-violet light. As before, the light will be absorbed at first, but in the end these physical elements or portions which absorb the blue-violet light will be destroyed, and the blue-violet light being no longer absorbed the portion absorbed will be blue-violet. Now let us take the case of the exposure of the black chromo-sensitive surface to white light. Putting aside certain qualifications and argumentative points, we may, for our present purposes, say that white light may be divided or plotted out into lights of the three colors above mentioned (see also page 35), red, green, and blue-violet. Assuming three original physical portions or elements in the black chromo-sensitive surface, it is obvious from what is said above that two of the three physical elements in the black surface are gradually destroyed by each of the above mentioned primary color-sensitive tints; so that when white light acts two destructive agents will be acting on each element of the black surface. At first all light will be absorbed—the surface is black—but as the three absorbent elements are destroyed, light ceases to be absorbed, and the surface becomes non-absorbent of all light. In other words, it becomes white, just as any surface must be visually white if it reflects at the same time and in due proportion the three primary color-vision tints, red, green, and blue-violet. Assuming now Wiener's view of the chromo-sensitive surface to be a correct one, it is easy to see that by a sufficient exposure to any colored projection or under any color transparency all the tints of the original will be reproduced, as by combination of red, green, and blue-violet all color tints can be reproduced to the eye. In addition, the ideal chromo-sensitive surface as supposed by Wiener would also reproduce monochrome; the camera image would be reproduced as a positive and in its true colors. It appears, however, to the author of the section that the rudimentary color elements of the color sensitive material should be regarded as complementary to the primary color sensation tints; in which case the above explanation will serve *mutatis mutandis;* but obviously if the structure of the chromo-sensitive material is granular, so that each color-element is isolated, the colors should be as stated above, and not complementary. (See mention of Cros's Composite Film, page 20.)

Wiener's chromo-sensitive surface has not by any means been fully realized in practice, although there are notable steps towards it, and if realized the problem of the fixation of direct heliochromes might still remain unsolved, although steps towards its solution will be mentioned farther on.

Wiener's Views as to the Seebeck Effect and Color Mimicry.

Certain animals of low type have the property of color adaptation or color mimicry; the property of assuming the color of their surroundings; this property being most notable in the case of certain larvæ and pupæ. Wiener suggests that this change, sometimes very rapid, as Darwin and others have pointed out, is due to a chromo-sensitive substance in the epidermis, but the subject is complicated by the fact that the change in color is ordinarily general even if the exposure to colored light is local. Wiener's speculations as to the intermediary action of nerves and nerve centers may bear a little on the problem of photography by telegraph, but do not appear to bear sufficiently on the general problem of color photography to be given at length here, although they open up new problems for the biologist, and indeed for all students of science.

Steps towards the Production of the Ideal Chromo-sensitive Surface. Herschel.

Seebeck's observations and those of some others have been mentioned in the historical summary and as bearing on the possibility of building up the chromo-sensitive surface by admixture of three plant or flower-stains. Wiener mentions some early experiments of Herschel (1842), in the course of which the coloring matter of certain flowers was said to be bleached by light of a tint complementary to that of the flower-stain. The complementary color of any one of the primary color-vision tints mentioned above would be the resultant obtained by uniting lights of the two remaining color-vision tints so this observation of Herschel—if established—should take us far on the road towards a building-up of a chromo-sensitive surface with three suitable fugitive organic coloring materials, which in their assemblage on paper would absorb all light (that is, be black), but which, when bleached out in totality, should give white; and when bleached out selectively by colored light should give all tints. In spite of the fact that I cannot find the actual observation of Herschel to which reference is made, there is much in his very extended series of observations on photography with vegetable coloring materials to suggest that a composite chromo-sensitive surface may be built up with three suitable fugitive coloring substances. At any rate, this possibility is worth bearing in mind. A long account of Herschel's photographic experiments with the coloring matters of flowers is contained in the first edition (1851) of Hunt's Photography, pages 119 to 126.

The Photo-salts of Carey Lea.

In the course of a research published in the American Journal of Science during 1887, M. Carey Lea demonstrated that the sub-chlorides, bromides, and iodides of silver may take an almost endless

variety of colors, the most common range being from white through flesh colors, pink, rose, copper red, red purple, and dark chocolate to black. These colored sub-haloids may be formed by the direct combination of the metal and chlorine, bromine, or iodine (as in Becquerel's method), by partially reducing normal haloids by the reaction of sub-oxide of silver with hydracid, and indeed by many similar reactions. Carey Lea called these sub-haloids "photo-salts," because they appear to be very similar to or identical with the sub-salts resulting from the action of light on the normal haloid salts of silver. In the present connection it should be understood that the term sub-haloid is used in a very loose sense, and not as implying the normal argentous haloid salts; but the photo-salts may be intimate mixtures of argentic and argentous chlorides with the soluble colloid silver of Lottermoser and Mayer; in which case the term sub-chloride would hardly apply, even when the word is used in a very free sense.

The Red Silver Photo-chloride.

Of all the photo-salts the red or reddish form of silver photo-salts appears to offer most promise in relation to heliochromic research. There are, as already suggested, many ways of producing it, but the following is perhaps the simplest and most instructive. Weigh out forty grains of silver nitrate, dissolve it in one ounce of water, and add enough hydrochloric acid to precipitate the whole of the silver. Agitate well in a four-ounce bottle, so as to make the precipitate agglomerate, allow it to settle, pour off the liquid without minding a loss of a little of the precipitate. Fill the bottle two-thirds full of water and pour off three times in succession to wash the precipitate. Now fill the bottle one-third full of water, and add strong liquid ammonia, a little at a time, until the precipitate dissolves, taking care to use as little ammonia as possible. Next is added sixty grains of protosulphate of iron dissolved in just so much water as will dissolve it. The black precipitate which forms is allowed to settle, the clear liquid is poured off, and the precipitate is washed in succession with dilute sulphuric acid, dilute nitric acid, and with water. At this stage the precipitate will be deep red, almost like copper slightly oxidized by heat. This and other red forms of the photo-chloride were found to assume a pure violet color in the violet of the spectrum; in the blue it became blue or slate-blue. The red rays in no way changed it, but in the green and yellow a bleaching action was noticed; this being of special interest in relation to Wiener's views, as in the green and greenish yellow we have a color complementary to that of the sensitive material. Under colored glasses Carey Lea obtained somewhat brighter colors than with the spectrum. Carey Lea continued experimenting with the photo-chlorides more or less up to the time of his death, but at best we can only consider that he was on the verge of this very com-

plex subject; still his researches give some hope of the discovery of the true color sensitive substance or mixture. The following summary, written in 1887, will show that he partly, at least, recognized the position since clearly defined by Wiener. Carey Lea said: "There is certainly here a great and most interesting field for experiment; hardly any two specimens of photo-chloride giving exactly the same results with colored light, and this suggests great possibilities. . . . The action of light on photo-chloride can be a good deal affected by placing other substances in contact with it. Any substance capable of giving up chlorine seems to influence the action somewhat; ferric chloride often acts favorably, also stannic and cupric chlorides. Evidently an important point in all heliochromic processes is that, as white light must be represented by white in the image, it is an essential condition that white light must exert a bleaching action on the sensitive substance employed. Red chloride does not bleach, but darkens, in white light (Carey Lea did not appear to realize the full significance of the red form bleaching under the action of the green rays); but the property of bleaching to a very considerable extent may be conferred upon it by certain other chlorides particularly by lead chloride and zinc chloride."

Experiments by Dittmar and Neuhauss. A step towards the Chromo-sensitive Material of Wiener.

Farther on (page 16) will be found a reference to some experiments by Dittmar, who uses a sensitive surface prepared as follows: Wood spirit or crude methylic alcohol 350 grammes, fuchsine, or magenta, 30 grammes; thymol, 8 grammes. These materials being boiled together and filtered, glass plates are coated; it being desirable to warm the plates before coating. Dr. Neuhauss in repeating Dittmar's experiments found that plates thus coated, or plates coated with a mixture of fuchsine and gelatine, may act like Wiener's chromo-sensitive surface. The Dittmar plate if exposed to sunlight for some days becomes violet-black, and if in this state it is exposed for a sufficiently long time under a colored positive transparency, this latter is reproduced; obviously the long exposure required puts this method of working outside practice, to say nothing of the question of fixation; but the observation is of importance as confirming Wiener's views and giving hope that with a single coloring material of an organic nature, the chromo-sensitive surface may one day be realized. In connection with this use of an organic coloring matter, reference may be made to Herschel's observations page 13).

The Beauregard effect, or asserted color control by an ordinary negative or print.

In a subject only just forming itself into tangible shape, even assertions which appear very contrary to received notions require

at any rate a mention, otherwise some germ of truth or clue to a new line of research may be lost. It has been repeatedly asserted that an ordinary negative or print has some power of color control which may show itself either by a selective power for coloring materials or in printing on a prepared surface. In 1855 and 1857 Testud de Beauregard made communications to the French Photographic Society and showed specimens in support of this view and he appears to have convinced many eminent men. In 1889 Mr. C. V. Boys, a gentleman well known as an accurate observer and a careful experimenter, made some observations on the adhesion of colored pigments to a chromated organic film, which was apparently of the ordinary kind, and presumably had been exposed under a transparency derived from a usual monochrome negative. Mr. Boys said (Photographic News, 1889, p. 458): "The colors do not appear to adhere indiscriminately, but to fall into their proper places as if directed by an unseen hand. For instance, in a landscape that I saw copied by this process, the blue powder was first dusted on and then a suitable tint of green. On examination it was found that the sky was blue and the leaves of the nearer trees were green, while the more distant trees were of a slightly different shade, giving the effect of distance perfectly."

Similar assertions as to latent color effect have been made by Herr Dittmar, of Venden; this investigator having definitely asserted that a single colorless negative or positive may control the colors of a print. Herr Dittmar prepares a sensitive surface as explained on page 14, and after a rather long exposure under a transparency the plate is developed in water; but at this stage the image shows no colors. The plate is now soaked in a one-half per cent. solution of caustic alkali and then in chlorine water, or in a solution of chlorinated soda; and after this the colors appear on exposure to air. The colors thus obtained are undoubtedly largely untrue to nature, and it need scarcely be said that very clear evidence would be required to establish any transmission of color effect through a single negative of the usual kind; although by Ducos du Hauron's system of plotting out a negative into three systems of lines, each system equivalent to a single negative of the heliochromic triplet, one monochromic negative plate may become a means of producing positives in a close approximation to the colors of nature (see page 49).

Col. St. Florent's Direct Heliochromes with an intermediate Monochrome stage.

At a meeting of the French Photographic Society, Colonel Saint Florent indicated a method of producing fixed and permanent heliochromes on silver chloride, thereby making a distinct step in advance. A piece of collodio chloride printing-out paper was exposed to the full light of the sun for from eighty to one hundred seconds, this exposure being sufficient to make it reddish black. The blackened

paper was then soaked in a bath composed of alcohol 100 c.c., glycerine 7 c.c., tincture of iodine containing one per cent., 7 c.c., and ammonia 6 drops. In this preparation the paper was allowed to remain for ten minutes, after which it was allowed to dry in a dark place, and was exposed under a colored transparency of glass or gelatine until the colors were all rendered, this generally involving an exposure of about one hour in sunshine. The print is next to be fixed in a ten per cent. solution of hyposulphite of soda. In the fixing bath the colors brighten and finally disappear, or almost disappear, the impression becoming of a clear yellow color. The next step is to wash the print and to dry it in sunshine, before a clear fire, or by ironing between sheets of blotting paper. During this latter operation the colors reappear. Colonel St. Florent, in spite of the conclusions of Wiener as regards somewhat similar results, considers that the colors in the present case are due to interference.

G. Wharton Simpson's results on a Collodio-Chloride of Silver Surface.

Going back chronologically to some observations of Mr. Wharton Simpson, the discoverer of collodio-chloride of silver, we get a close touching point with the work of Colonel St. Florent; and we may perhaps gather from both that collodio-chloride of silver affords promise of leading to practical results in relation to direct pigmentary heliochromy, a department in which, at the time of writing, practical results seem rather remote. Mr. Simpson, writing in the *Photographic News* of 1866, page 73, reviews the earlier experiments in direct pigmentary heliochromy, and fully recognizes that the heliochromic surface must be one first made dark colored (as by a general exposure) and details several experiments with special samples of collodio-chloride of silver, and in which no color effect or practically no effect was produced. Remarkable results were, however, obtained with "a fresh sample of collodio-chloride of silver, to one ounce of which about two grains of chloride of strontium and five grains of nitrate of silver were added, the object being to prepare a collodio-chloride with the slightest possible excess of nitrate of silver." Mr. Wharton Simpson's various papers and notes on collodio-chloride, which had been published before the date of the above mentioned experiments are very verbose and the modes of mixing are such as cannot be briefly described, but reading them together with the paper on heliochromy it is quite clear that he means a collodio-chloride, in the preparation of which the above quantities of chloride of strontium and silver nitrate are used in making up each ounce, and a calculation of equivalents suggests that he used dried, and not crystallized, chloride of strontium. It also appears by the context that no citric acid was used. The following is probably a close equivalent to the preparation he used, and is at any rate a good basis for experimental work. To make about eight fluid

ounces of collodio-chloride, take 2 fluid ounces of absolute alcohol, and add to it a solution of 40 grains of silver nitrate dissolved in about 45 minims of water. Now add 40 grains of a pyroxyline of a kind suitable for negative collodion, but not giving too tender a film. Shake well, and finally add 2 fluid ounces of ether. Call this "silver collodion," or A. Now take 2 ounces of 90 per cent. alcohol (New Brit. Pharm. Standard), add to it 40 grains of pyroxyline as above, shake, and add 2 ounces of ether. In this collodion dissolve 16 grains of anhydrous chloride of strontium finely powdered; or, more conveniently, 20 grains of crystallized chloride of strontium. Call this "chloride collodion," or B. For use, mix equal volumes of A and B. Mr. Simpson coated a plate of opal glass with this emulsion, dried it before the fire, and exposed it to diffused daylight until it assumed a deep lavender gray tint or slate color. Several pieces of colored glass and material were then laid on the film, and the whole was exposed for some hours to sunlight. Under ruby glass the film had become bright claret or magenta; under orange glass it was orange, but more inclining to red than the color of the glass. Under white glass, which had been covered with an aniline red, the film was orange, but this color graduated into a deep purple red where the aniline color on the covering glass had run into a pool or ridge. Under glass covered with green aniline color the film was green, the green being deepest where the color on the covering glass had run into a ridge. The glass on which the aniline colors had been spread was slightly yellow, like many samples of patent plate, and under those parts of this glass upon which there was no aniline color, the film bleached to a yellowish white, while at the margins, where there was nothing over the collodio-chloride film, the darkening action continued until the film became deep bronze black. Mr. Simpson, who was a careful observer, apologizes for publishing results apparently so fruitless in practical results, but explains that his chief object is to point out to others engaged in similar research the great advantages of collodio-chloride of silver as a starting point.

Looked at from the point of view of possibly leading to a working method, Mr. Simpson's experiments and those of Colonel St. Florent, in which fixation has been realized, are perhaps the most important hitherto made in connection with direct pigmentary heliochromy. Just as Mr. Simpson speaks of the orange as reproduced being redder than the covering glass, so Colonel St. Florent remarks that yellow tends to reproduce as red.

All direct heliochromic experiments tend to show that the color sensitiveness of darkened chloride of silver depends on conditions which are not yet thoroughly understood, and that slight and scarcely noticed differences in the mode of preparation may have considerable influence on the result; it is, however, desirable to give a selection of such instructions as have been given by the most careful workers, although perhaps nothing so near to a practical working process in

direct pigmentary heliochromy has been given as the process of Colonel St. Florent (page 16), the prints in this case being fixed.

Becquerel's Method, on Silvered Plates.

Becquerel (see also pages 5 and 9) made many experiments and published many working directions for obtaining his heliochromes on silver plates, heliochromes which are partly pigmentary, and, as Wiener has shown, partly due to interference. Of all methods for so chlorinating the silver plate as to produce a thickness of chloride which shall be completely under control, Becquerel preferred chlorinating the silver surface by making it the positive in an electrolytic decomposing cell, the nascent chlorine uniting with the silver. A sheet of platinum forms the negative plate and twelve and one-half per cent. hydrochloric acid is the liquid in which the plates are immersed. Owing to the action of atmospheric oxygen upon the hydrochloric acid, a very slight chlorinating action will take place if the silver plate and platinum plate are connected by means of a conducting wire, the two plates and liquid forming a voltaic cell; but it is better to effect the chlorination in a very large glass bath containing the dilute hydrochloric acid and to use two small bichromatic cells as a source of current; this arrangement allowing of an adjustment of the current not only by a more or less considerable immersion of the zincs of the battery, but also by varying the distance between silver plate and platinum plate in the hydrochloric acid bath. The carbon terminal of the pair of bichromatic batteries should be connected with the silver plate, and the zinc terminal of the pair of batteries should be connected with the platinum plate, as shown by Fig. 3.

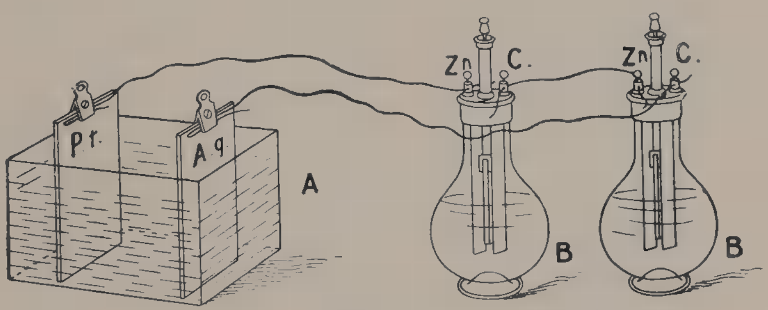

Fig. 3.

A, electrolytic cell containing platinum plate, Pt; and silver plate, Ag; both immersed in 12½ per cent. hydrochloric acid. Two cells of bichromate battery BB are connected as shown; Zn standing for zinc and C for carbon.

The current should be so adjusted that at the end of a minute the film becomes gray, afterward yellowish, then violet and blue, after which the same series of tints is seen to be repeated in the same order; but directly the violet color is seen for the second time the

silver plate is removed from the bath, washed in water, and dried at as low a temperature as practicable over the flame of a spirit lamp. The plate is now sensitive to all spectral tints, but the green is shown less satisfactorily than the other colors. If the plate is dried at a rather high temperature, it becomes reddish, and is then more especially sensitive for the yellow color.

Charles Cros's Composite Black Film.

It will be seen from the account of Wiener's ideal chromo-sensitive material that it may be supposed to contain within itself three colored pigmentary elements, each of these pigmentary elements being destroyed by light of a tint complementary to its own color. This view was in a certain sense anticipated by a practical attempt by Charles Cros in 1881 to realize the composite black film by covering a plate of glass or enamel paper first with collodion colored red with carthamine, then with gelatine colored blue by phyllocyanine, and finally with collodion made yellow by curcuma. The essential condition is so to tint the media and so to adjust the thickness of the several films that the result is a black or neutral tint. Such a film will, by long exposure under a colored transparency, give a more or less perfect replica of the colored image, but the result depends upon the fugitiveness of the pigments, and the prints obtained are unfixed.

A Method in which Commercial Printing-out Papers will serve.

Herr Kopp, of Munster, found that many kinds of commercial gelatino-chloride or collodio-chloride-emulsion papers will give direct heliochromes by the following process, the results being remarkably striking in some instances, but only medium in others. According to a slightly modified form of his methods the well-washed paper is immersed in a dish containing a weak acidified solution of chloride of zinc; chloride of zinc, 2 grains; sulphuric acid, 2 drops; water, 5 ounces. While in this bath the paper is exposed to light until it becomes bluish-green, this change being a first indication that success is probable with the sample of paper under trial. The paper is now thoroughly washed, blotted off, and it may be preserved in the dark for some days. Half an ounce of potassium bichromate and half an ounce of sulphate of copper are now dissolved in three and a half ounces of hot water, and to the solution is added half an ounce of mercurous nitrate dissolved in the smallest possible quantity of water, this water being very slightly acidified with nitric acid. A large quantity of water decomposes the mercurous nitrate. The mercury solution is now stirred into the hot bichromate-copper solution and the mixture is allowed to cool. The liquid must now be adjusted to 100 c.c. by evaporation or dilution, filtered from any deposit, and the bluish-green paper is allowed to remain in it for half

a minute, during which time it will lose most of its color. After blotting off, the paper is allowed to remain in a three-per-cent. solution of chloride of zinc until it becomes once more bluish-green or blue. It is now once more blotted off, thoroughly washed, and exposed while damp under the colored original, a sheet of talc being interposed if the original is of a kind to take harm by contact with the damp paper. During exposure the greens and yellows will appear, and when the sheet is dry these parts must be painted with a resinous varnish (*e.g.*, sandarac in alcohol) as a resist. The sheet is soaked in two-per-cent. sulphuric acid to develop the other colors, after which it is washed and finally treated with alcohol to remove the resinous material. Weak chloride of zinc fixes the image to some extent.

General Note on the Rendering of Natural Colors in Heliochromic Processes.

It is often said that it is much easier to reproduce the spectrum or a painting by heliochromic methods than it is to produce natural scenes, but this probably arises from the fact that monochrome is the chief factor in natural scenes, considerable areas of color being the exception; the most vividly colored objects reflecting much white light, especially at oblique incidence. Painters ordinarily exaggerate the color effect, and a heliochrome which is true to nature will therefore often convey the impression of being too dull. As a matter of fact, direct pigmentary heliochromes are ordinarily somewhat too dull in color effect, while interference heliochromes are usually too vivid as regards color. Synthetic, or three-color heliochromes, may be too vivid or otherwise according to the selection of pigments and other conditions.

CHAPTER III.

INTERFERENCE HELIOCHROMY.

Optical principles involved. Touching points with direct pigmentary heliochromy. Fundamental work of Zenker. Wiener's experiments. The work of Lippmann and his followers.

TRANSPARENT bodies having a laminated structure decompose light under certain conditions; familiar instances being afforded by mother of pearl, a soap bubble, the layer of air enclosed in a fractured piece of glass, disintegrated or scaly glass, and a film of oily matter on the surface of water. It may be generally stated that all transparent bodies, whether solid, liquid or gaseous, appear very brightly colored if in sufficiently thin layers, and these colors of thin laminæ appear especially bright when viewed by reflection; but in every case the color by transmission is exactly complementary to that by reflection.

The phenomena of the colors produced by thin plates or laminæ are best studied by following some of the original experiments of Newton, and considering them in relation to the undulatory theory of light.

In order to produce a thin plate of air of graduated and known thickness, Newton took a plano-convex lens, shown by A, Fig. 4, and placed this upon a flat slab of glass, B, as shown. At the point

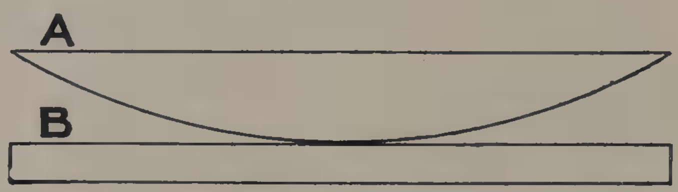

Fig. 4.

of contact the distance between the flat glass and the plano-convex lens is assumed to be nil; and if the curvature of the lens is known it is easy to calculate the thickness of the film of air at any given distance from the center; but instead of air any liquid medium may be between the glasses. If the convexity of the lens, A, is sufficiently slight and the two glasses are brought together with sufficient force to ensure something like actual contact at the central point, a series of colored fringes or rings will be seen around this central point, these colors being best viewed and studied by reflected light. The

colored rings arise from the fact that within rather wide limits the thin film of air will eliminate or destroy certain constituents of the white or ordinary light (see page 37 for composition of white light), and when any one constituent of ordinary or white light is removed the remaining light will be colored, its tint being said to be complementary to that of the color removed.

Any explanation of the destruction of any of the colored constituents of light by what is called interference almost necessarily involves graphic representations to assist the mind in an effort to symbolize that which in the present state of existence we cannot fully comprehend or express. It must be most clearly understood that the following representations of wave action are purely symbolical, and are not to be considered in any sense as showing actual conditions.

Let us represent the wave-like propagation of a ray of monochromatic light by a sinuous line, A, Fig. 5, and assume B to repre-

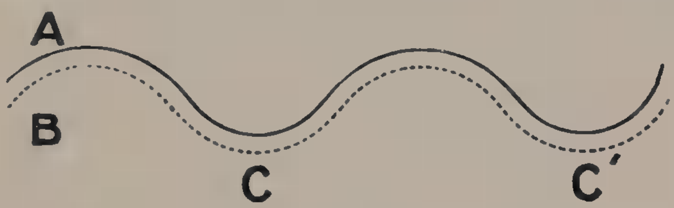

Fig. 5.

sent another ray of the same color (pitch), and breadth of swing or intensity. These two, coinciding in path, pitch, and swing, may be assumed to coalesce and to give a wave of double strength or having a swing of double force. Let us now assume a case in which the phases of one wave are exactly opposed to those of the other. We may now take it that, in a sense, the two wave motions neutralize or destroy each other, and Fig. 6 may serve as a graphic suggestion;

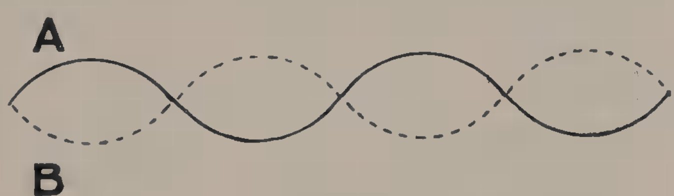

Fig. 6.

but this figure or a similar one has occasionally been used as symbolical of another matter in dealing with the problem of interference heliochromy (see page 25), hence the student cannot too clearly recognize the purely symbolic nature of all graphic representations of wave motion. If the two interfering wave motions figured by the two lines of Fig. 6 are exactly equal in color or pitch and in intensity (or swing) and the opposition of phase is exact, the extinction should perhaps be absolute If the intensity of the two waves is unequal

the intensity of the resultant should be the difference of these intensities.

By Newton's researches with the thin film of air we know that when the thickness of the film of air is such as to correspond to the half-wave length of any incident light (for the moment we must of course assume monochromatic light, as this alone has a single wave length) the light is extinguished by reflection, and when the thickness of the film of air is one-fourth of a wave length the light is not extinguished by reflection, a matter easy to understand by interference as explained above. It might at first sight appear that when the film of air is of a thickness equal to one-fourth of an undulation, the ray reflected from the under surface of the air film having to traverse the thickness twice would lag behind to the extent of a half wave length, and so would destroy the ray reflected from the upper surface of the air film, whereas the reverse happens. According to Young, the explanation is to be found in an essential difference in the nature of such partial reflection as takes place when the ray leaves a medium for one of higher refractive power and that which takes place when the ray leaves a medium for one of lower refractive power; the vibration of the particles (of ether) in the reflected ray being reversed in the former case but not in the latter. A very striking experimental confirmation of Young's theory is to be found in the fact that when a film of oil of sassafras is formed in Newton's apparatus (Fig. 4) and one of the glasses used has a higher refractive index than the oil (Flint glass) while the other glass has a lower refractive index than the oil, the reverse conditions will hold good, and a film having a thickness corresponding to half a wave length of any ray will reflect while a film having a thickness of one-fourth of a wave length will extinguish.

Out of Newton's experiments and Young's further study of the subject of the colors of this film we thus arrive at the following conclusion which has a very fundamental bearing on the process of interference heliochromy.

A film of any transparent substance which is situated between media of higher and lower refractive power respectively will show, by reflection, a color corresponding to that of light having a wave length equal to double the thickness of the film.

In the above concise statement it must be understood that by wave length is meant wave length in the medium of which the film is composed, and that the incidence of the light on the film is supposed to be vertical. It being made clear that a thin transparent film can under certain circumstances select out from white light and reflect to the eye that particular tint of light which corresponds to a wave length of double the thickness of the film, the theory of interference heliochromy will be complete for simple spectral tints when it is shown how the agency of the colored rays themselves can form

one film or another which may fulfil the above conditions. It is not necessary to tell the readers more concerning the phenomena of Newton's rings; the effect of greater and multiple thickness, and the various influences which complicate the phenomena as ordinarily observed.

The photographic film for interference heliochromy must be one which is highly transparent and practically structureless, but otherwise it may widely differ in its nature. A transparent film of gelatine containing a very small proportion of a perfectly emulsified and transparent silver bromide is specially suitable and is ordinarily used. Another essential condition is that the light after having passed through the film should be reflected back so as to produce what are known as stationary or standing waves; the term being perhaps somewhat of a misnomer, but the "standing waves" at any rate correspond to alternations of chemical activity and chemical inactivity situated at a distance of half a wave length apart. In this way light of any given color (that is of any given wave length or pitch), if it impinges on the sensitive film with a reflecting surface behind, can produce a periodic structure in the film, the elements of which structure are half a wave length apart; and one at least of these elements will be able to reflect that color of light which has produced it.

Let Fig. 7 represent a much magnified section of the sensitive film, with portions of the glass plate and the mercury mirror. The solid lines represent the entering waves, and the dotted lines the outgoing waves as reflected from the mirror. Such rays as fall as shown will interfere with more or less complete extinction; the so-called standing waves or nodal planes being formed on the axis where the interference is most complete, the loops representing the

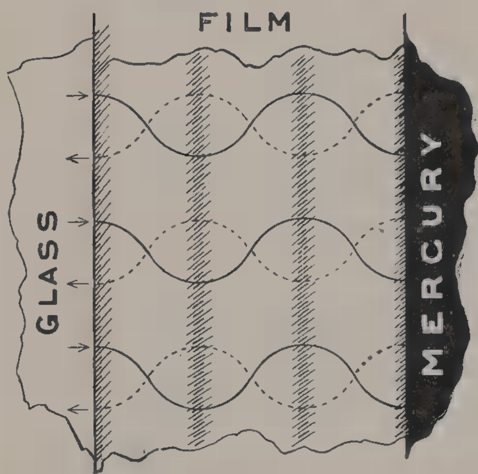

FIG. 7.

planes of greatest chemical action, which chemical action is shown by shadings. We must assume Young's loss of half a wave length in the mere act of reflection, this being shown separately by the terminations A and B. The mercury in this case acts like a substance with a higher refractive index than the gelatine; although it is a moot point whether a "refractive index" can be assigned to mercury, in the strictest sense of the term "refractive index." Still the phase reversal, on reflection from the mercury, must be taken into account in any right understanding of interference heliochromy. Phase reversal, when light is reflected from mercury in contact with glass (a strictly comparable fact), was demonstrated by the author of this section at a meeting of the Royal Photographic Society, held on April 25, 1899. A glass bulb separated into equal parts by a diaphragm so thin as to show Newton's rings was partially filled with mercury, when the phase reversal became obvious by the colored rings changing to complementaries where the mercury was in contact with the thin diaphragm. The method of making the diaphragmed bulbs and conducting this experiment is described in the Journal of the Royal Photographic Society for May, 1899, page 252.

A pretty illustration of the formation of the so-called standing waves by reflection is obtained if a rope about as thick as an ordinary clothes-line and some thirty feet long (or, better still, an india-rubber cord) is fastened by one end to a nail and the other end is held in the hand and set in motion so as to produce waves which travel to the nail and back. This experiment was shown by Professor Lippmann in explaining standing waves in a lecture delivered to the Royal Photographic Society in 1897.

The Wave Length of Light.

Strictly one cannot definitely speak of the wave length of light in a general sense, but only that of any particular color in the spectrum (see page 37 for a short account of the spectrum) and in relation to a given medium; but the following short table of the wave lengths of light and air and for certain definite spectral positions (see page 37) may be of use.

Position in Spectrum	*Wave length in millionths of a Millimetre.*
A line (extreme red)	759
D " (clear yellow)	589
E " (green)	527
F " (Prussian blue)	486
H " (violet)	397

The above numbers if divided by twenty-five will give approximately the wave lengths in millionths of an inch. In media denser

than air the wave lengths are shorter; wave lengths for other media may be considered to be inversely as the refractive indices for the extreme red. A wave length is always taken as including the complete phase; as from C to C1 in such a symbolic representation as Fig. 5.

Touching points between Direct Pigmentary Heliochromy and Interference Heliochromy.

In another place (page 11) it is explained how Wiener showed that Becquerel's direct heliochromes were partly due to interference, but it is interesting to note that W. Zenker, of Berlin, in his *Lehrbuch der Photochromie,* published at Berlin in 1868, put forward the theory that all direct heliochromy on chloride of silver is due to interference, and in spite of Wiener's clever method of distinguishing between pigmentary effects and interference effects it is impossible to draw an absolute line. This will be further apparent by a study of the effects obtained by Graby and others with somewhat irregular reflecting surfaces.

The work of Zenker.

Zenker in the Handbook of Photochromy above referred to and published at Berlin in 1868 puts forward a complete theory of interference heliochromy, and sufficiently indicates lines of work to lead an intelligent operator in a path towards practical results. Like M. Ducos du Hauron's work on three-color heliochromy, Dr. Zenker's book was almost lost sight of. Professor Lippmann called attention to it, and brought the labors of Zenker to a practical issue. Zenker pointed out that if heliochromes are to be produced by the interference method the laminæ producing a given color must not only have a determinate thickness from the beginning, but this thickness must be maintained after fixation or completion, a condition impossible in the case of flocculent chloride of silver. Furthermore, he pointed out that for the reproduction of any given color the laminæ must correspond to the wave length of that color.* Zenker must be considered as having laid the scientific foundation of interference heliochromy.

Wiener's success in recording the Stationary or Standing Waves on a Photographic Film.

In 1889 Otto Wiener sought to demonstrate the existence of

* Under the conditions defined on page 25 the film may be of half a wave length, a wave length, and up to a certain point any super-multiple of a wave length in thickness. As far as experience goes the best results may be hoped for with the thinnest films or smallest practicable number of laminæ. Those wishing to refer to a concise and lucid treatise on light in relation to chemical processes in general may be referred to the articles on light in Vol. III. of the original edition of Watts's Dictionary of Chemistry. Longmans, Green & Co. 1868.

stationary or standing waves by photographic means, and in the first view of the subject he rejected such sensitive surfaces as the ordinary gelatine plate, as the thickness of the film would be enormous in relation to the record to be made, and, moreover, far too coarse in texture. He obtained some of two solutions ordinarily sold for producing "collodio-chloride of silver" by their admixture, and he diluted these to fifteen or twenty times the original volume before mixing them. In this way he obtained a colorless and transparent collodio-chloride emulsion, and a plate coated with this could scarcely be distinguished from an uncoated plate. By placing a mirror in contact with or at a slight inclination to such a plate he obtained a definite photographic record of the stationary waves. A similar record was obtained on thinly silvered glass plates sensitized by fuming with iodine. This work is of the greatest importance, and, taken in conjunction with Dr. Neuhauss's recent production of microphotographs of sections of an interference heliochrome, may be considered to fully establish Zenker's theory of interference heliochromy.

The work of Lippmann and of his followers.

In 1891 M. Gabriel Lippmann laid the foundation of a practical method of interference heliochromy based on the theory of Zenker and on the work of Wiener, the merits of both of these pioneers being fully recognized by M. Lippmann. As a process, that method of interference heliochromy which every year becomes easier and more certain is due to M. Lippmann, and it may reasonably be called—as it ordinarily is—the Lippmann process. The general account of this method of working cannot be better and more concisely given than in the words of Professor Lippmann himself when he, in faultless English, addressed a meeting of the Royal Photographic Society in 1897.

The apparatus is very simple and differs scarcely in any particular from that which is used for ordinary work. You have simply to take a transparent sensitive film of any kind; you are not bound to any particular substance; you may take, for instance, gelatino-bromide or albumino-iodide of silver, or any other transparent sensitive film. The film must be transparent and grainless, such as the specimen I show you, quite free from cloudiness or milkiness. You have then to expose it in the camera, taking care that during exposure it is backed by a metallic mirror, which is easily formed by a layer of mercury; you have simply to take a dark slide and make it mercury tight, lay the plate in the slide, and allow the mercury to flow in from a small reservoir at the back, so that the sensitive film on the glass plate is now backed by mercury, forming a mirror. When the plate has been exposed in the camera in the ordinary manner for the requisite period, the mercury is allowed to flow back into the reservoir, and the plate can then be removed and treated with pyro-

gallic acid, amidol, or any other appropriate developer, and fixed, washed, and dried in the usual manner; while the plate is wet the colors are not visible, but they appear as it gradually becomes dry. Except for these two important details—the mercury mirror and the transparency of the plate—the technique of the process is exactly that of ordinary photography. The first object of which I took a photograph was the spectrum; as a physicist I had to take the spectrum, because it is composed of simple colors, and the problem is thus simpler than where composite colors are concerned.

Now, how is it that we see the color? The photographic operations are the same as in ordinary photography, the result of the operations is the same, a similar deposit of reduced silver is obtained, and the materials of which the image is composed are the same as those in a colorless plate. The difference is that the deposit has acquired such a structure that it decomposes the light by which it is illumined, and sends back to the eye of the observer elements of white light, which together make the natural colors of the object. In the same manner the colorless drops form the rainbow. A soap bubble appears colored, although consisting of a colorless solution, and mother of pearl appears colored, although made of colorless carbonate of lime. It is a phenomenon of interference due to the structure which the deposit has acquired; if you were to use a plate without a mirror you would get an ordinary negative, but the presence of the mirror changes everything, and this is how it is done: You know that light is made up of vibrations, just as sound is; these vibrations give rise to light waves that rush through the ether and the plate with a velocity of 300,000 kilometres per second; therefore, they impress the plate more or less strongly, and thus leave a design of different intensities of the image, but as they rush through the plate they leave no record of their own form. And this is what I mean by their own form: each ray of light of a certain color has a certain structure; it is made up of waves which have a certain wave length; you know a wave length is the distance between the crests of two succeeding waves; red has a comparatively great wave length, blue has a much smaller one, and the intermediate colors have each a distinct and intermediate length of wave. If you put no mirror: each train of waves rushes through the plate, and wipes off every record of its own form by reason of its velocity; you cannot expect a thing which moves with the velocity of 300,000 kilometres in a second to give a photograph of itself. If you put a mercury mirror behind the plate, then the following phenomena occur: the light is reflected back on itself; the light rushes in with a velocity of light and rushes out again with the same velocity; the entering and issuing rays interfere, and the effect of the interference is that vibration takes place: but the effects of propagation are stopped, and instead of having propagated waves we get stationary waves; that is, the waves now rise and fall, each in its own place; they pose, therefore, in the interior of the film and impress their form upon it, the largest move-

ment giving the strongest impression, and where the movement is naught the impression is naught. So that you have the form of the vibration impressed in the interior of the film by the photographic process, and the photographic film has really acquired now the structure of the incident rays because they have become stationary and impressed their form upon it. The result is that, if you look through the film, you see nothing special; it looks like an ordinary negative; but if you look at it by reflection, then you see it colored. And this for the following reason: Suppose at one place the plate has been impressed by red light, the red light has impressed its structure on that part of the plate, and that part of the plate is now able to reflect back to our eyes only the red part of the white rays—only the red element which is a component part of white light, and similarly with every part of the spectrum; it is a mere mechanical adaptation of the form of the deposit to the form of the light vibrations.

Now, this is a theory; we want some confirmation of the theory, to show by experiment that the colors we see are really due to interference. There are a good many demonstrations of that; one of them is that you get the colors by any chemical means which give you a fixed photograph; you are not obliged to take a silver salt; you can work, for instance, with bichromate of potash and albumen, or bichromate and gelatine, and get colored photographs. Moreover, there are a good many experiments which can be made to show that the colors are really due to interference; I will show you only one of these, which is as follows: I have told you already that the colors are not visible while the plate is wet; you must wait until it is dry. If you take the dry picture, and make it wet, the colors disappear; if, instead of plunging it into water, you breathe upon it, so as to make it somewhat damp, the gelatine swells and you see the colors gradually change and disappear, and they gradually return as the drying takes place. What is the reason? It is that the gelatine or albumen swells by the action of water, and the interference between the maxima in successive planes is enlarged and has no longer the value necessary for reflecting a particular element of light; as the drying proceeds the film contracts, and the proper colors gradually return. Another proof of the theory is that the interference colors change with the incidence; if, for instance, you look slantingly at a soap bubble you will see the red turn successively green and blue, and the same in the case with these photographs which I am about to show you—they must be viewed at the normal incidence; if you look at them slantingly you see the colors change, the red turning successively to yellow, green, and blue.* Moreover, the colors appear only when you look at the photograph in the incidence of

* Observations of this kind (as to the changing colors of the feathers of the peacock's tail or of the pigeon's head) form part of Lucretius's celebrated argument (about 60 B. C.) that color is not a property of matter but an accident depending on the relation of matter to light. See his *De Rerum Natura*, Book II., 729 to 840.

regular reflection; that is, you have to let the light fall on the photograph and put your eye in the direction of the regularly reflected ray; if you look from another point you see only a colorless negative. If the colors were laid on with a brush you would not get that effect, for you would see the colors the same in whatever incidence; this is rather a fortunate circumstance, for it makes the touching up with ordinary colors impossible and proves the authenticity of the photograph.

That is the first part of the problem, the part which most interests the physicist, namely, to fix the simple colors of the spectrum; but, of course, we all want to have other colors fixed—the colors of nature. These are composite colors, as you know, all—however complex they seem—of the rays of the spectrum; so that the question is, Will a superposition of simple colors give the same effect as if each simple color were separated? Here again, as we might expect, the experiment succeeded, and I will show you some results obtained by photographing various kinds of objects. The mathematical theory is somewhat more complicated. I will simply say that it is very much akin to the theory of the rendering of composite sound by the phonograph. The theory of the phonograph is very simple if you consider only simple sounds; if you consider composite sounds—the sound of the human voice—the sounds are made up of simple sounds, and they are rendered by the phonograph as perfectly as simple sounds; the theory of that is the same as the theory of the superposition of simple vibrations. I will now simply show you my results, which you will see include every composite color, and that white is reproduced equally well. It is necessary to use an isochromatic plate, transparent and grainless, as before, back it with mercury, expose, and develop.

The exposure given in the case of a portrait taken by M. Lumière, and now exhibited, was, I believe, about a minute, and the same period sufficed for a view at Biarritz; in Paris an exposure of from two to three minutes is required for similar subjects. The pictures have been projected for your inspection by means of a megascope; that is, the light is sent from the electric source on to the photograph, and is reflected by the photograph through the projecting lens on to the screen. As color sensitizers, I used cyanine for red, and quinoline red for green, in very small proportions—about one-fiftieth of a milligramme to 100 grammes of emulsion, or one part in 500,000 parts. For twelve years my investigations were impeded on account of the difficulty which I experienced in the preparation of a transparent film; I tried solutions of bromide of potassium and nitrate of silver in water, of various strengths, and always got a precipitate, which is not surprising; but I had not thought that if, instead of using pure water, you use water containing gelatine or albumen you get no precipitate, and by adopting that method I solved the difficulty. I add the color sensitizer before coating the plates; very good results may be obtained by dipping, but they are not quite

so satisfactory. I have tried to reproduce the pictures by printing in contact with another plate, but have not yet succeeded in doing so, although I am quite sure it is possible; the only condition necessary is that the plate will show complementary colors by transparency, and these can already be made faintly visible. If the film bearing the image were stripped from its glass support and the superficial area enlarged, a new set of colors would be produced in consequence of the change in wave length; the alteration is analogous to that which occurs when the plate is wetted, but in the opposite direction, the film in that case swelling, whereas, if expanded superficially, it would be reduced in thickness. If the colored photographs are viewed obliquely, the colors tend to blue rather than to red, a fact which is observed also with regard to soap bubbles, Newton's rings, and all interference phenomena, because the difference of wave between the two rays which interfere is composed not only of that part of the way which is in the interior of the laminæ, but there is a small exterior way.

When working in sunlight it is advisable to place before the lens a screen to cut off the ultra-violet rays; when projecting the images, a better result is obtained if a piece of black glass is cemented to the back of the plate for the purpose of preventing reflection from the back. There is a certain degree of elasticity in the exposure required, but I think much less than in monochromatic photography; this arises from the fact that we keenly appreciate differences in color, whereas differences in gradation in monochrome are not so noticeable. If the component parts of any given color are not in the proper proportion we get a change in color; for instance, if there is too much red in what ought to be white you will see it green, and the eye is very sensitive to that; if you do not expose and develop properly you have no proportionality between the deposit and the intensity of vibration, and the color will change. The most suitable thickness of the sensitive film is secured by flowing the gelatine over the plate as with collodion, the film being then about one-twentieth of a millimetre thick, say as thick as a piece of cigarette paper. A copy or an enlargement in colors could be made from an original by projecting the image in the manner which has been done to-night, a sensitive film backed with mercury being substituted for the screen of white paper which has been used here. For ordinary examination the plates must be looked at as a Daguerreotype is viewed, and the colors are easily discernible in diffused light.

The Reflecting Mirror of Mercury.

As already explained, the exposure of the sensitive film takes place through the glass and with a reflecting surface of mercury on the other side of the sensitive film.

The mechanical arrangements for holding the mercury against the film may be very simple; a bent strip of india-rubber, shown by

A, Fig. 8, forms the sides and bottom of a cell of which the front is the sensitive plate, film inwards, and the back is a plain glass plate. In this place there is no occasion to sketch the actual form of dark slide that it is convenient to use in practice.

Fig. 8.

Interference Heliochromes without the use of a Mercury Cell.

According to the accepted theory of the formation of the Lippmann heliochrome, reflection at the back of the film or in the film is an essential, but Krone found that some traces of Lippmann effect may be obtained if a glass plate with a suitable transparent film is exposed in the camera in the ordinary way, reflection from the glass giving rise to the necessary standing waves. Further, several observers have obtained heliochromic effects when reflecting particles were enclosed in the film; but obviously only very faint color can be expected, as only the light incident normally or nearly so on the particles will tell. Interference heliochromy without the mercury mirror is only interesting as a bare possibility, the tints being almost necessarily dull.

Lippmann's Formula for Emulsion and Developer.

Although a wide range of choice is available as far as the selection of the sensitive material is concerned, if the essential conditions of transparency and absence of structure are fulfilled, Professor Lippmann appears all through to have given preference to a gelatine bromide emulsion, and his most recent instructions are as follows: *Emulsion.*—In 100 c.c. of water allow 4 grammes of gela-

tine to swell, then add .53 gramme of potassium bromide, 6 c.c. of .2 per cent. alcoholic solution of cyanine, and 3 c.c. of .2 per cent. solution of chinoline red. When the gelatine has melted, and the temperature has fallen below 40 c., .75 gramme of dry powdered silver nitrate is added; this last addition being made in the dark room. The mixture is now well agitated for about two minutes, and is then filtered through cotton wool. The plates to be coated should be slightly warmed and the emulsion is poured on as if it were collodion. The plates as coated must be laid on a level slab for the film to set. When dry the films are wetted with alcohol. As each is wetted it is immersed in water, and the plates are allowed to soak for an hour. When once more dry they may be stored, but just before using it is desirable to increase the sensitiveness by flowing over the film a solution consisting of absolute alcohol 100 grammes, silver nitrate .5 gramme, and glacial acetic acid, .5 gramme, the excess being removed by swinging. When again dry the plate is ready for exposure. For a brightly lighted scene in sunshine and with a rapid lens the exposure will be about two minutes. *Development.*—I., water, 100 c.c.; pyrogallic acid, 1 gramme. II., water, 100 c.c.; bromide of potassium, 10 grammes. III., ammonia of S.G. .960 (one of strong liquid ammonia with about two of water). For use, take 10 c.c. of I., 15 c.c. of II., 5 c.c. of III., and 70 c.c. of water. Fixation is with weak cyanide of potassium. As a general thing it is best not to carry the development on so far as to produce full intensity, the image being subsequently intensified by the mercuric chloride method followed by amidol.

General Nature of the Lippmann Image.

The glass plate bearing the finished Lippmann heliochrome will generally appear much the same as a decidedly weak ordinary negative if held up to the light and viewed by transmission, as the various deposits or layers of silver obstruct the light; still more or less color effect will ordinarily be seen when the plate is viewed as a negative; and such color as is seen will be nearly complementary to the true colors of the objects. If it were possible to produce a Lippmann heliochrome of the spectrum in which each color produced but one lamina of a thickness equal to half a wave length, and there were no secondary actions, doubtless the plate if viewed by transmission would show colors exactly complementary (although fainter) to those seen by transmission.

When the Lippmann plate, which appears as a negative by transmitted light, is laid on a black surface and viewed by reflection, it is seen as a positive light being reflected from the silver deposit and absorbed where the glass is bare, as the black velvet then comes into play. So far any thin and unfogged negative on glass will show more or less perfectly as a positive; indeed, the old fashioned col-

lodion positives on glass as still occasionally made by outdoor photographers at seaside resorts are thin negatives which, when laid on a black surface and viewed by transmission, appear as positives. The Lippmann plate when thus viewed as a positive reproduces the various portions of the original scene as follows:

(*a*). The black. Where the velvet underneath is only covered by plain glass.

(*b*). The white. Where there is a general structureless deposit of silver.

(*c*). A pure or spectral color. Where there is a laminated deposit of silver, the laminæ being at a distance apart of half a wave length for that particular color.

(*d*). Compound tints. Where two sets of faint laminæ co-exist (see page 31).

Viewing the Lippmann Heliochrome.

In order that the interference colors may be seen so that the colors are true to nature the plate must be viewed by vertical incidence, a matter by no means convenient. If the plate is looked at more and more obliquely the red will become orange, yellow, green, and blue in succession (see page 36).

Projecting the Lippmann Heliochrome.

In order to see the interference heliochrome with comfort and as one looks at a picture, projection by reflected light is essential. M. Louis Lumière employs the arrangement shown by Fig. 9. A is

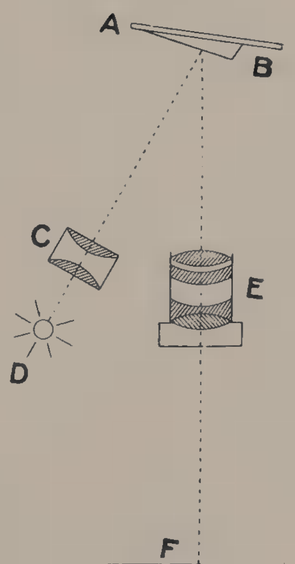

Fig. 9.

the Lippmann heliochrome, B is a glass prism cemented with Canada balsam to the heliochrome; the prism serving to divert direct and

disturbing reflections from the surface; C is the double condenser of the illuminating apparatus; D the position of the electric arc light used; E a portrait lens which forms an image on the white screen, F. The necessary casings required in this apparatus (virtually an ordinary aphengoscope or lantern for showing opaque objects) are not shown.

The Reproduction of Lippmann Heliochromes.

As may be gathered from what has been said, a Lippmann heliochrome should, if certain conditions could be perfectly realized, be capable of reproduction, by first making a transparent positive by printing with parallel light on a backed Lippmann plate, and from this similarly printing a transparent negative, or a reproduction of the original, but the transmission colors of the Lippmann plate are faint and partially untrue (see pages 34 and 35).

Unfortunately, there seems at present but faint hope of carrying out in practice that which appears simple in theory, but M. Lippmann appears to hope almost against hope. The nearest approach to the practical reproduction of the Lippmann heliochromes is by copying in the camera, the sensitive plate taking the place of the screen, F, in Fig. 9.

Wiener has recently (end of 1899) found that the light reflected from the outer gelatine surface is in phase-reversal with that reflected from the first internal layer of silver, and that this phase difference is a source of disturbance in viewing. Increased brilliancy is obtained by immersing the heliochrome in benzole, whereby the surface reflection is eliminated, or by coating with a film of collodion of such thickness as to put the surface reflection out of period.

CHAPTER IV.

SYNTHETIC OR THREE-COLOR HELIOCHROMY.

Underlying scientific principles. The far-reaching method of Louis Ducos du Hauron. The work of Ives, Abney, Joly, and others.

When a pencil of white light is split up into its constituent colored rays by a prism the resulting color scale or spectrum may be considered as formed of an infinite number of colors, each differing a little from the adjoining portions; but it is very customary, and indeed convenient, to speak of the seven spectral colors as named by Newton, but fixed positions in the spectrum can only be defined by reference to certain spectroscopic lines. The diagram, Fig. 10, may be taken as representing the spectrum, while on page 25 will be found

Fig. 10.

a table giving the wave lengths of light for certain standard positions. The spectrum is actually much longer than shown by Fig. 10, but the two ends, "ultra-violet" and "infra-red," are invisible to the human eye.

The perceptive organs of the retina or "focussing screen" of the eye are not so multiple in their character as would be the case if each one of a number of closely adjacent points in the spectrum was directly distinguished by a special series of nerve terminals, there being actually only three sets of color perceptive organs. In other words, each unit of vision for definition or sharpness appears to consist of three nerve terminals or fibrils, each of these fibrils being constituted to receive an impression of one tint of color; but the color sensation tints are not pure spectral colors, they are composite tints one of which may be spoken of as blue, another as red, and the third as green; their particular composite tints (hereafter to be more clearly defined) being commonly spoken of as the three-color sensation tints. The visible spectrum as a whole is made up (with certain overlapping) of three tints in equal visual intensity, and the spectrum as a whole will, if acting uniformly on any given area of the retina, give the impression of whiteness, each set of nerve fibrils being equally stimulated. The sensation of whiteness can be produced by any combination whatever of tints which equally stimulates the three sets of nerve terminals or fibrils. Still more, by taking any three combinations or colors which individually affect the three sets of nerve fibrils and varying the intensity of these any color sensation whatever may be conveyed to the brain. Thus it happens that, by combining three colored lights each of which only corresponds to a very short range in the spectrum, we can produce the effect of a complete spectrum to the eye, although in the physical sense the spectrum is not thus reproduced.*

The three tints selected for stimulating the three sets of color-sensation fibrils in the retina may be any three colors which by their union will produce the sensation of whiteness; and it may be generally stated that any three such tints may become the factors from which a full range of heliochromic effect is built up to the eye and the imagination, but not in reality. Such a heliochrome may have but little truth to nature in the case of a person whose perception of color is slightly abnormal, even though the person in question may be in no real sense of the word color blind. Such a heliochrome is at best a mere optical illusion, but this in no way militates against the artistic, esthetic, and industrial value of three-color heliochromy; still, a full realization of the above position is not only an essential to the understanding of the scientific basis of three-color heliochromy, but also to the carrying of it out in practice.

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* The principle of taking the heliochromic triplet in more or less strict correspondence with the color sensation curves, and viewing by simpler combinations which proportionately excite the three sets of color sensation fibrils, appears to have been overlooked by all workers prior to Mr. Ives.

The Color-sensation Curves.

We now come to a more detailed consideration of the effect of the spectral colors on the organs of vision, or in other words the constitution of the three primary color-sensation tints, a matter first explained by Young quite early in the nineteenth century and elaborately plotted out diagrammatically by Clerk-Maxwell; but these curves have recently been laboriously redetermined by Abney with modern appliances. Fig. 11 shows Clerk-Maxwell's curves,

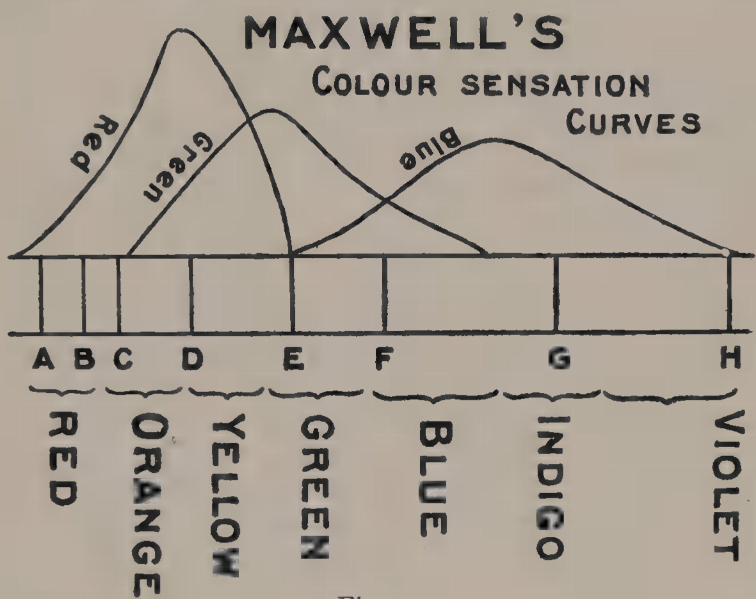

Fig. 11.

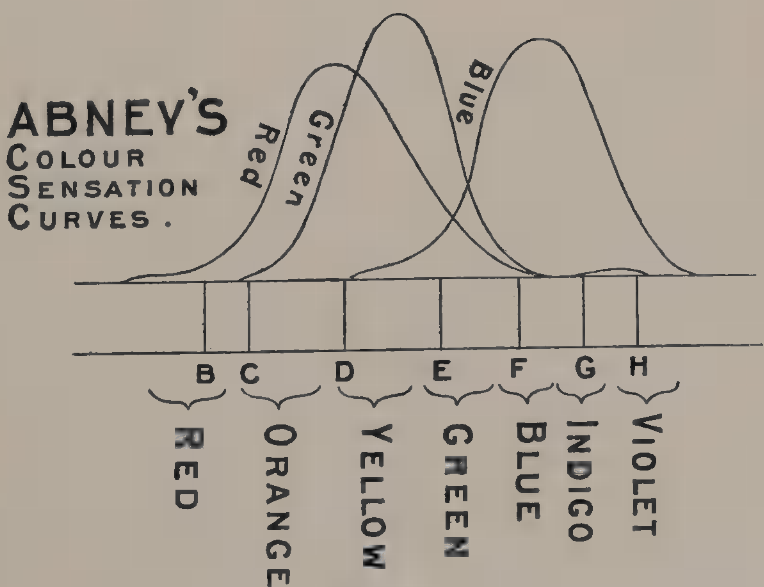

Fig. 12.

indicating the extent to which the various parts of the spectrum stimulate the three sets of nerve terminals of the retina, while Fig. 12 shows Abney's curves of the relations of the spectrum to the color sensations, as redetermined by him during 1898-1899; a work involving some nine months of close attention. At any given position the height of the curve indicates the intensity of the stimulus by that particular part of the spectrum.

A CRUDE OR GENERAL SUMMARY OF THE TRICHROMATIC METHOD OF HELIOCHROMY.

The general method of three-color photography may thus be stated. *Three negatives are produced by reddish, bluish, and greenish light respectively; and the nearer these tints correspond to those compound colors which excite the primary color sensations the better. The prints from these negatives are superimposed materially, by optical projection, or by a plotting out of minute parts of each side by side in line or dot; but the illumination or pigment by which the three positives become visible must be such that each positive excites the nerve fibrils corresponding to the color screen used in taking its own negative. When printing colors are superimposed the tints must be complementary to the reproduction colors above mentioned* (see p. 43).

In practice the question of color screens is very much complicated by the fact that no photographic plates yet produced represent the spectrum in degrees of monotone corresponding to the visual intensity, and there seems no immediate hope of producing such plates. A plate perfect in the above respect would of necessity be absolutely insensitive to the invisible ends of the spectrum.

It is interesting to note that the pioneer work on color photography, Louis Ducos du Hauron's "*Les Couleurs en Photographie,*" published by Marion in 1869, contains a full enunciation of the above principle, and such practical instructions as were possible with the materials and appliances then available. Ducos du Hauron not only explained his process but produced excellent results. Color sensitized plates were not known at the time this book was published and the three negatives were simply taken under colored screens, but in the specification of an English patent dated July 22, 1876, the use of plates sensitized with aurine, eosine and chlorophyll is described. The above mentioned book, the specification of 1876, and the early specimens of Du Hauron show him without doubt as the originator of synthetic heliochromy on true principles, as distinguished from the early speculations of Collen and Cros (see p. 6), of which erroneous principles were the basis. To thoroughly do justice to Louis Du Hauron the following extracts may be given from the official abstract of his patent-specification of July 22, 1876; and this can be done with all the better reason as this extract gives a concise statement as to three-color heliochromy unrivalled as

regards clearness. The following are the words of the official abstract:—"*Three negatives of the same subject are obtained;* one by green light, the second by orange light, the third by violet light. Three positives or monochromes are respectively printed from these negatives; the positives are on semi-transparent paper prepared with the complementary colors. The three semi-transparent monochromes, being superposed, represent, by the blending of the tints, the total color of the object taken. . . . Aurine or eosine is used in sensitizing the negative from green light, and chlorophyll in that from orange light." As regards the use of the "orange" screen in taking the negative corresponding to the red sensation, Ducos du Hauron fully explains that it should be red-orange, and that it is used as a kind of compromise for red owing to the difficulty of photographing by red. In this matter recent workers have largely followed Du Hauron especially in that form of his process in which the three negatives are taken on one plate, under a screen ruled in the three colors.

The work of F. E. Ives.

Doing full justice to Du Hauron in no way detracts from the merits of the second chief pioneer in three-color heliochromy, Mr. Ives, of Philadelphia, whose work has gone far to make three-color heliochromy a commercial reality, and who has overcome many obstacles to the making of his three original negatives correspond very closely to the three primary color-sensation tints.* Mr. Ives has pointed out that for the red-sensation negative we may use a gelatino-bromide plate with a double screen of collodion stained with chrysoidine orange on the one hand and an aniline yellow on the other hand. For the green sensation negative, a gelatino-bromide plate stained with cyanine and erythrosine is exposed with a screen colored with an aniline yellow; while for the blue-sensation negative an ordinary gelatino-bromide plate is used with a double screen of chrysophenine yellow and red-tinged methyl violet.

Mr. Ives, like Du Hauron, takes his negatives with a special camera in which the original bundle of rays coming from the object is split up by plates of glass so placed as both to transmit and reflect; the principle of such an apparatus being indicated by Fig. 13. The bundle of rays A from the object is partly reflected and partly transmitted by each of the plates of glass B and C, whereby an image of the subject is simultaneously produced in what are virtually three separate cameras, D, E, and F. Fig. 14 indicates the principle of a similar arrangement involving the use of but one lens; while Fig. 15 is another and later form actually in use as a viewing device. The number of devices of the above nature is now very great, but very few involve any fundamental departure from the principles

* See footnote on page 38 for statement of an important principle first laid down by Mr. Ives.

involved in the above. In a taking device such as Fig. 13, the requisite color screens may be in front of or behind the respective

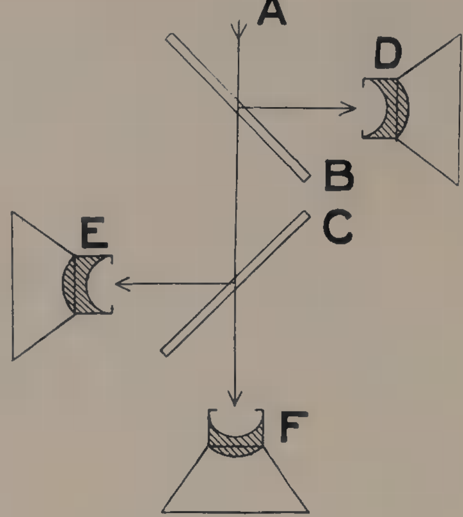

Fig. 13.

lenses, or one at least of the two reflecting plates may serve as one color screen. In the case of the viewing device for transparencies, Fig. 15 (called by Mr. Ives the Kromskop), A, B, and C are respectively red, blue, and green glasses, against which transparencies from

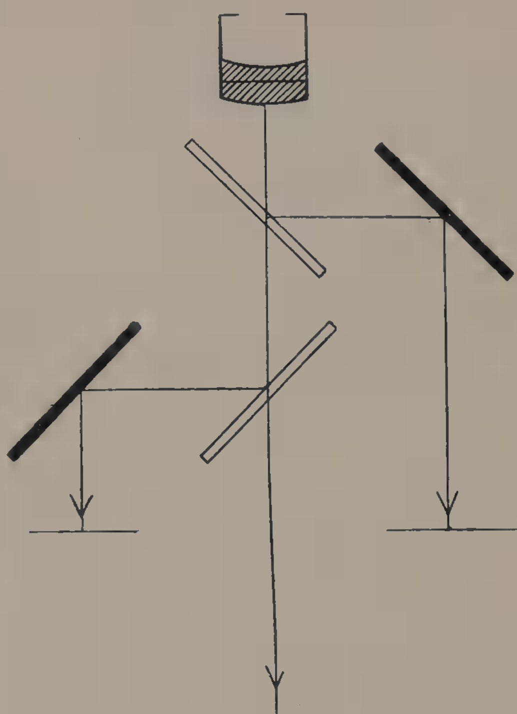

Fig. 14.

the corresponding negatives are laid, and behind is a reflector, so placed that light coming from one source may illuminate all three transparencies. This form of apparatus has the special advantage of being easily made double so as to be suited for stereoscopic subjects; and obviously a similar pattern may be used as a camera.

Mr. Ives produces some of his best effects by triple projection; each transparency of the heliochromic triplet being backed up with a colored glass, these glasses being red, green, and blue as in the viewing arrangement, Fig. 15. In this case separate images are formed which unite by superimposition on the screen.

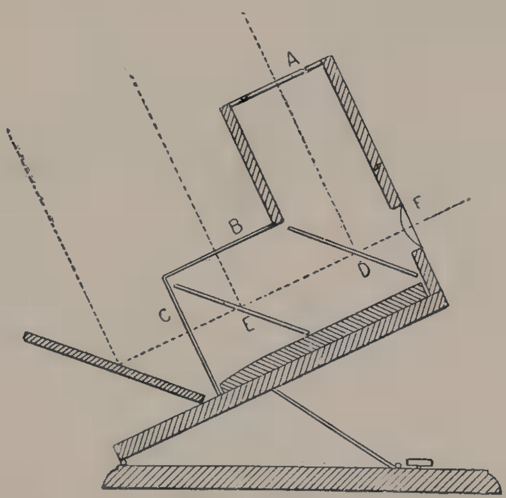

Fig. 15.

Colors for transparencies by superimposing films, or for prints in pigment.

In projection or in viewing, as above described, the colored glasses used with the transparencies correspond approximately with the color-sensation tints, and this will be understood when it is remarked that the simultaneous action of all three colors in undiminished strength (as in the whites of the original scene) will give the effect of whiteness to the eye. When, on the other hand, three colored films or three layers of pigment are superimposed, the effect will be blackness or opacity, if the colors of the films or pigments are such as to produce the effect of whiteness when mingled. This is because such light as any two pigments or films allow to pass the third pigment or film cuts off. Hence it is that, as explained by Ducos du Hauron in his first work on heliochromy, the printing colors or the colors for staining superimposed films must be complementary to these colors by which the three negatives were taken. Thus in making a composite heliochromic transparency for the lantern by superimposition of three colored films, Mr. Ives used a lemon

yellow transparency from the negative corresponding to the blue color-sensation, a Prussian blue transparency from the negative corresponding to the red color-sensation, and a magenta pink transparency from the negative corresponding to the green color-sensation. The first test of the suitability of these film staining colors is that when superimposed blackness or opacity shall result, just as the first test of the colored lights for viewing in the photochromoscope (or Kromskop, Fig. 15) is that when united they shall produce the effect of white. A very severe test of any process in which stained films or pigments are used is to include on the same plate a half-tone photograph in monochrome and a subject in colors. Mr. Ives in the course of his lecture demonstrations has shown such a lantern slide, composed of three films colored as above. When used as an ordinary slide in an ordinary lantern the monochrome and the colored subjects were shown with remarkable perfection; but when the films were separated each film was shown as brightly colored with the above-mentioned tints, complementary to the color-sensations. A test like the above is one of greater severity than many people would think, whether in the case of a print in colors or a transparency in colors.

An illustration of the use of complementary colors for printing.

As so many workers have found a stumbling block in the matter of the printing colors being complementary to those for triple or separate projection (p. 43), or for viewing in the photochromoscope (Kromskop, p. 42), it may be well to trace through the formation of a single colored image in each case. Let the subject be a line in full indigo blue on a white sheet. This blue line will be rendered as a clear or transparent line on the red-sensation negative and on the green-sensation negative, while its effect on the blue-sensation negative will be negligible. The positive from the blue-sensation negative will therefore be practically clear glass, while the two remaining positives (from the red-sensation negative and the green-sensation negative) will each bear an opaque line corresponding to the original line. In the photochromoscope, therefore, while the ground appears white by the union of all three lights the line will be blue, as on its area all light but the blue will be cut off from the observer. If now a print on paper is made from the same triplet of negatives, the negative corresponding to the blue-sensation becomes inoperative as it is uniformly opaque; while the negative corresponding to the red-sensation gives a line in prussian blue, and the negative corresponding to the green-sensation gives a superimposed line in magenta pink. The magenta pink destroys that green element of the prussian blue with which magenta pink is complementary, and a full or indigo blue line is the result.

Captain Abney's researches and contributions to three-color heliochromy.

The work of Captain Abney in connection with heliochromy generally is referred to in other places, but as regards three-color heliochromy or synthetic heliochromy we have in the various writings and researches of Abney a very full record of scientific or theoretical progress, to which progress Abney's own researches have very largely contributed. In 1881 and 1882 Abney contributed to the Photographic Journal a noted translation of Eder's Chemical Effect of the Spectrum, and in 1883 these chapters were reprinted in book form (The Chemical Effect of the Spectrum, London, 1883. Harrison & Sons). Here we find the fullest recognition of the work of Ducos du Hauron and a very full explanation of the theoretical basis, especially of that much misunderstood point; taking by green, red, or orange* and blue screens, and printing with red, blue, and yellow. Abney writes (1881-1883): "After long researches Ducos du Hauron produced colored photographs in the following manner. . . . He produces in the camera three different images; that is to say, one by green, another by orange, and another by violet light, and the model is photographed through glasses thus colored. . . . The red monochrome is obtained from the negative made with green light; the blue monochrome from the negative given by orange light; and the yellow from a negative taken with violet light. Why are three different negatives? and why also this diversity—this *chassé croisé* of colors?" Then follows the explanation.

A somewhat popular exposition of the subject given by Captain Abney as a paper to the Society of Arts in 1898 was of a specially useful character as calculated to appeal to those who might be confused by the importation of the Young-Helmholtz color sensation theory. He commenced by showing the spectrum on the screen, and pointed out that at first glance the obvious elements of the spectrum are red, green, and blue, other colors being incidental. Next he pointed out that these basic sections of the spectrum, red, green, and blue, may, if united in different intensities, give to the eye the effect of all the various tints which we see in the case of the natural objects around us. By arranging a series of overlaps of the basic tints, red, green, and blue, he showed that red light and green light unite to make yellow, blue and green unite to give the greenish-blue or bluish-green sometimes called peacock blue, while blue and yellow make white. Then by suitable adjustments of the three slits controlling the spectral red, green, and blue, so as to allow regulated proportions to pass, he showed that all natural tints can be reproduced. In trichromatic printing, he explained, this control is by the three photographic originals. He assumed, now, the

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* See page 40 for Ducos du Hauron's definition.

problem to be the representing of flat surfaces of equal brightness in the following seven colors, and he explained that the solution would consist in photographing them on three different plates and taking transparencies from them so that on each transparency the colors shall be represented as indicated below; transparency being represented by T and opacity by O.

	No. 1 plate.	No. 2 plate.	No. 3 plate.
White	T	T	T
Red	T	O	O
Purple	T	O	T
Yellow	T	T	O
Green	O	T	O
Blue-Green	O	T	T
Blue	O	O	T

If now No. 1 be backed with a red medium, No. 2 by a green medium, and No. 3 by a blue medium, these media being of such a density that when the lights coming through these media are superimposed, the above combinations will, if each is projected and superimposed on a screen, give the colors named in the list.

Captain Abney's Color Sensitometer.

The above was introductory to a description of the principle of Captain Abney's color sensitometer, which has already done excellent service, and appears destined to become an important aid in the heliochromic work of the future. The principle of this instrument was thus described: " Take a number of small colored squares of glass, such as are enumerated above, which only allow certain colors to pass through. Choose the three colors with which the three transparencies are to be backed, and by mixture of these standard colors find out how much of each of them is required to match the colors of the glasses, both in intensity and hue. Measure the brightness of the light coming through the colored glasses, then to make a sensitometer to enable you to choose the proper screen for taking the red negative, as I will call it, reduce the brightness of the different glasses to the extent which is necessary to cause all the red light required to come through the different colors to be of equal density. Then in a proper negative all of the deposits should be of equal opacity, and for any brand of plate used a screen must be sought for which will give this result. Take another similar set of glasses and reduce the transmission of them so that the green transparency should allow equal light to penetrate, and a screen must be sought for till such is the case. The same for the blue. We thus shall have found three screens through which to photograph to give us three transparencies from the three negatives that when backed with the chosen colors, red, green, and blue, will give us the true colors of the objects."

Captain Abney on the Colors for Printing.

In the course of a lecture, with experimental demonstrations, to the Royal Photographic Society in 1899, Captain Abney summarized the question of colors as bearing on the practical side of trichromatic printing, and as a preliminary he exhibited on the screen a diagram of his redetermination of the color-sensation curves; then he very strongly emphasized that in taking the triplet of negatives these curves must be the basis of work, and the deposit on each must have a strict physical correspondence with the incidence of these curves. Pigments nearly corresponding in their visual effect to spectral light plotted out according to the Color Sensation Curves are (1) Vermilion washed with a little transparent blue, to take off the yellowness of the scarlet, (2) Emerald Green, and (3) True Ultramarine. These may be plotted out as a guide chart to aid in the selection of the complementaries for use as printing colors; but the pigments used in making the ink must not only be exactly complementary to the sensation tints, but must be transparent, and at least as permanent as are the colors ordinarily used by the water color artist. To produce such an ideal triad of printing inks is now a problem for the ink-maker and practical color manufacturer. The standard of color is obviously better referred to the spectrum than by naming pigments, as there is always a standard of reference, and Captain Abney mentioned certain positions in the spectrum as viewing colors or projection colors for reconstituting the color scene to the eye, and in doing so he again emphasized that the curves and not isolated colors must be the basis in taking the three negatives; in fact, all the spectral rays must take part in making the negatives, but for reconstituting the scene to the eye we must select tints corresponding to very limited ranges of the spectrum, without that overlapping which is characteristic of the color-sensation curves. The spectral colors to be used as standards for viewing or projection are red, a little below C, green near E, but one-tenth the distance towards F. Blue, the position of the blue lithium line.* The colors of the printing inks used in trichromatic work should be absolutely complementary to these for projection. Printing green complementary to the above, spectral red will be an apple greenish blue, while the printing red complementary to the above spectral green will be a kind of magenta pink, and the printing yellow complementary to the above spectral blue will be a greenish-yellow; these complementaries must overlap as little as possible, or, in other words, they must correspond to separate parts of the spectrum or the prints will be muddy and incorrect in coloring. Captain Abney's paper is to be found in the Journal of the Royal Photographic Society, March, 1899, page 192.

* Wave length 460 millionths of a millimetre and about midway between F and G; but a little nearer to the former than the latter. See p. 37 for diagram of the spectrum, and p. 26 for a table of the more important wave lengths.

Captain Abney on plates for the most perfect effect.

Ordinary or unstained plates are, Captain Abney points out, the only plates which will most perfectly reproduce all spectral tints, as every part of the spectrum acts on the ordinary plate, although with very unequal intensity; still, without dark clouds or patches in the spectral image, a point Captain Abney illustrated by projecting upon the screen the spectrum as photographed upon various color sensitized plates and upon ordinary plates. Obviously the ordinary plates must be used with sufficiently intense screens corresponding to the color sensation curves, and the relative exposures for the three negatives will be about as follows: "Red" negative 100; "Green" negative 8; "Blue" negative 1. Obviously, for ordinary commercial work, which of a necessity involves somewhat of a compromise with scientific principles, color sensitive or stained plates will be used in order to lessen the above wide difference of exposure for the three negatives.

Work at the Imperial State Paper Office, St. Petersburg. A turning point in trichromatic printing.

In 1893, when trichromatic printing was beginning to be talked of as an industrial possibility, the Experimental Staff of the Imperial State Paper Office of St. Petersburg produced some examples of three-color collotype, which were so remarkably successful as to convince printers all over the world that trichromatic printing might be of great industrial value. Soon after this the leading color printers in all parts of the world made arrangements for trichromatic printing from surface blocks, and to this experiment we probably owe the present position of trichromatic printing. The St. Petersburg experiments were, it is said, undertaken at the initiative of the Czar, and were carried out by Herr Weissenberger.

Some variations of the photochromoscope.

During the last few years a considerable number of variations of the Photochromoscope have appeared; and indeed there is scarcely a limit to the modifications which may be made on the original idea of Louis Ducos du Hauron. Among those which may be mentioned is one due to Messrs. Lumley, Barnard, and Gowenlock, in which the apparatus is simplified by taking advantage of the fact that two colors seen by the two eyes respectively are superimposed to the sense, as in the case of the stereoscope, hence but one reflector is required. This apparatus, as far as one eye is concerned, is sufficiently illustrated by Fig. 16, A being the transparent reflector, while B and C are two portions of the triplet. The third positive is seen with the other eye, and it is convenient to make the reflector A long enough to serve for both eyes and to duplicate the trans-

parency in the positive C. Obviously this apparatus would equally well superimpose four transparencies if there were occasion to do so. The apparatus in question, if used as a camera (of course with suitable modifications) will give a stereoscopic effect, complete as far as the top transparency C is concerned, but otherwise partial.

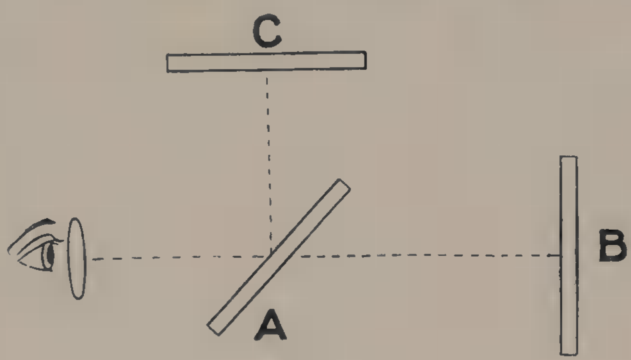

Fig. 16.

Synthetic heliochromy with a single composite positive and a ruled color screen.

This method, suggested as far back as 1869 by Louis Ducos du Hauron* and discussed by several writers since, appears to have first been put into successful practice at the initiative of Professor Joly, who in this matter has overcome practical difficulties which at the outset were regarded by many as unsurmountable. Indeed, when Professor Joly read a paper on this phase of three-color heliochromy (Dublin Royal Society, June, 1896) the general impression was that, however possible the method might be as an operation in a physical laboratory, there could be but little hope of more than this.

In order to make the method clear it must be explained that the single negative first taken really includes three negatives, and the following considerations will show how it is possible to take three or more perfectly distinct negatives on one plate and to view any one of these—or the positive print from it—separately. We will assume that the area of a sensitive plate is plotted out into narrow strips numbered 1, 2, 3—1, 2, 3—1, 2, 3, and so on until the whole area is covered. If all the No. 1 strips are exposed we shall have the essentials of a negative, but it will be discontinuous, and obviously will cover only one-third of the area of the plate; but if the strips into which the plate is plotted out are sufficiently narrow, the subject will appear continuous and perfect to the eye. In a similar way we may have a totally different subject on the No. 2

* See Du Hauron's "Les Couleurs en Photographie," Paris, 1869, Marion, page 54.

strips, and a third subject on strips No. 3. All that would be required to produce the three subjects on one plate would be to place in front of the plate, when exposed, a screen evenly ruled with opaque lines twice as wide as the transparent strip intervening. After the first exposure the screen is shifted by as much as the width of the transparent strip, and another subject can be impressed, the same being done before the third exposure. Such a composite negative would give a transparency showing a jumble of the three subjects, but the ruled plate used to partially screen the negative plate during exposure could be so placed over the transparency as to cut off any two subjects, when the third would flash out clearly and isolated; but by shifting the screen one or two degrees the transformation would be complete to either of the other subjects. In the single-plate process of three-color heliochromy the first requisite is a gelatino-bromide or other plate equally sensitive to all parts of the visible spectrum; as in this case, differential exposures cannot be given—at any rate not without importing extreme complication into the method. In front of the negative plate and in contact with the film is supported the color-screen plate, upon which very narrow strips are ruled in transparent colors, which colors should accurately correspond to the color-sensation curves. Exposure thus produces three separate negatives, and a positive transparency having been made, this transparency is placed in contact with a viewing screen, which should be ruled in strips to the exact gauge or measure of the taking screen; but the colors on the viewing screen, although generally similar to the eye to those required on the taking screen (approximately red, green, and blue), should be single spectral tints which do not overlap much, and which respectively stimulate the three-color sensations of the eye.*

The positive transparency and the viewing screen having been brought into adjustment with each other by means indicated below, each of the three positive transparencies will be backed up by the correct viewing color, and the elements of the heliochrome will be so interlocked that all will appear continuous and as one to the eye, giving the effect of the original object.

Special Limitations of one-plate triple heliochromy.

At present no plate quite fulfils the theoretical needs of the one-plate method, and the system of compromise cannot be distributed over three plates as in the case of the method with separate negatives. As regards the color screens there is, quite apart from the mechanical difficulty of ruling, a little more difficulty than in the

* The theoretical needs as regards these colors are the same as in the case of ordinary three-color heliochromy, but the special difficulties and limitations incident to the one-plate method make it generally desirable to use a red for the taking screen which tends a little to orange, and in other respects slight compromises are almost unavoidable, as will be seen from the description of the method of working.

ordinary method. Fugitive colors are alone available, and the complex screen when faded cannot be replaced quite in the easy fashion as can single films of stained collodion.

Ultra-violet rays which would chiefly harm the blue impression must be cut off by a general yellow screen (gelatine stained with picric acid) and this almost of necessity disturbs the balance of color. As regards the fineness of the ruling on the screens, a choice must be made between a screen so coarse as to show texture and one so fine that when the positive is viewed at somewhat oblique incidence across the lines the positive is seen in relation to the wrong screen lines, at any rate where irregularities on either plate prevent close contact.

Special advantages of the one-plate process. The heliochromic negative serving as an ordinary negative.

Taking and viewing screens may now be obtained commercially (manufactured by the Natural Color Photograph Company of Dublin), and if used with the Lumière panchromatic plates or Cadett spectrum plates very surprisingly good results may be obtained, without further incumbrance or inconvenience either at home or on tour, than the use of the two screens (ruled screen and light picric acid screen). This use of the screens is but a trifling inconvenience from a mechanical point of view, as an ordinary dark slide may be used, but a longer exposure than usual is required. Still negatives and positives will serve as ordinary negatives and positives until it is wished to use them for color effect.

The One-Plate Process in Practice.

The ruled colored screens being obtained from the manufacturers mentioned above, all other steps are easy and simple. The screen is placed in the dark slide and against its ruled side the sensitive film of the plate rests; the simplest way of dealing with the focussing question being to focus back a distance corresponding to the thickness of the screen. The light yellow screen for cutting off the ultra-violet rays is best fixed in the camera immediately in front of the dark slide. A negative plate on thin glass may be fixed in hypo, without exposure, and after washing the clear gelatine film it is slightly stained with a solution of picric acid; the intensity should be so adjusted that when using the above-mentioned plates and photographing a white to gray object there is no great preponderance of density in those parts of the negative under the blue lines of the screen. This effect under the individual lines can only be seen through a magnifying glass, and at this stage there will be no difficulty in distinguishing the "blue" line, as two will almost certainly show equal density. Instead of the yellow picric acid screen mentioned above a light greenish yellow screen of

optically worked glass may be used either before or behind the lens. Nothing special need be said as to the development of the negative or the making of the positive transparency, merely good ordinary photographic work being required; extreme density is, however, bad in either case. The adjustment of the viewing screen to the positive may be temporary, or permanent by binding with edge strips is in the case of ordinary lantern slides. The positive transparency and the color screen being held together face to face, a position can almost instantaneously be found in which bands of color crossing the image and indicating a want of parallelism disappear, and in which the tints become true. If considered necessary, an object of standard color may be included in the scene, or a strip of magenta dye in varnish may be painted on the extreme edge of the sensitive plate. Beyond the above no special instructions are required for producing heliochromes by the one-plate method; and of all heliochromic methods this is by far the easiest for beginners or amateurs.

The making of individual prints for the heliochromic triad of negatives. Gum bichromate.

The value of three-color heliochromy rests principally in its use in connection with block, collotype, or other printing processes, but individual prints may be made by purely photographic methods, one of the easiest being to employ the now well known gum-bichromate process; making up gum-bichromate mixtures with the necessary pigments and printing from the three negatives in succession on the same sheet. After one impression is completed the paper is coated with the second mixture, exposed and developed, after which the third color is similarly dealt with. Mr. Brewerton somewhat simplifies this proceeding by first making a print from the blue-printing negative on Ferro-prussiate paper, and then using gum-bichromate mixtures on the same sheet for the red print and the yellow print.

Professor K. Noack, of Giessen, employs the following composite method: Whatman's drawing paper is squeegeed, when wet, to a glass plate, flooded with a 6 per cent. gelatine solution, allowed to dry and the coating is hardened by immersion of the sheet in a 5 per cent. formalin bath. The sheet is sensitized by being floated from four to six minutes on a bath prepared by mixing the following solution: A, water, 40 c.c.; caustic soda, 0.35 gramme; B-naphthol, 1 gramme. B, water, 40 c.c.; sodium tetra-azo-ditolyl-sulphonate, 1 gramme; saturated solution of sulphite of sodium, 2 drops. This paper if blotted off and dried will keep fairly well, but at the time of exposure under the *red-printing negative* it must be slightly damp. Exposure is rather less than for a printed-out silver print. Fixation is by repeated treatment with a ½ per cent. caustic soda solution, followed by a 10 per cent. acetic acid bath, and washing. The same sheet is made sensitive for the yellow

impression, by being floated (while still damp) for five minutes on a bath of equal parts of the following: C, water, 250 c.c.; glacial acetic acid, 25 grammes; nitrate of lead, 20 grammes. D, water, 250 c.c.; ferricyanide of potassium, 30 grammes. The exposure is long (about 5 hours in the shade on a bright sunlight day). The exposed sheet is rinsed several times in water acidulated with ½ to 1 per cent. of nitric acid, washed in water, and immersed in a weak bichromate bath (20 c.c. of a saturated solution of bichromate of potassium in 100 c.c. of water) where the lead deposit becomes yellow. Another washing is necessary, and if traces of Prussian blue have been deposited, clearing in a weak ammonia bath, followed by 10 per cent. acetic acid, is desirable. The blue impression is made by the ordinary cyanofer method, but a second coating or wash of gelatine is necessary, as the combined red and yellow impressions clog the pores of the first coating. The sensitizing solution for the blue impression consists of equal parts of the following: E, water, 200 c.c.; double citrate of iron and ammonia, 50 grammes. F, water, 200 c.c.; ferricyanide of potassium, 50 grammes. It is as well to add 10 c.c. of a 2 per cent. solution of citric acid to each 40 c.c. of the mixture. The fixing of the blue impression is by mere soaking in water.

The multitude of "processes."

Now that three-color heliochromy is showing itself industrially valuable many professedly new processes have been brought before the public, but none of them offer such fundamental departures in method as to require notice in this section.

A HANDBOOK OF PHOTOGRAPHY IN COLORS.

SECTION II.—BY ALEXANDER A. K. TALLENT.

Three-Color Photography.

SUMMARY

AND

LIST OF CONTENTS.

Preface.

Principles and Practice rest on satisfactory basis due particularly to two workers.

Sir W. Abney proved that the sensation of color is amenable to measurement, made quantitative researches on color, and introduced the necessary methods and apparatus. His methods of application of photography to the quantitative record of color are of *extreme* importance in this subject.

Mr. Ives accepted the three-color theory of vision, showed the application of photography to it, and placed the theory on a sound basis, invented instrumental means and methods, and introduced them for public use.

Inferior results are no longer acceptable. Color work is exacting, and necessitates accuracy, importance of quantitative experiment, and proper methods of practice. Further research needed.

List of Authors. Books and Articles.

Introductory.

The peculiar property of photography of recording exactly, rapidly and automatically. No new photographic processes involved. Knowledge of color essential.

The early experiments of Professor Clerk-Maxwell.

Professor Vogel discovered Orthochromatism.

The work of Mr. Ives.

DIVISION I.—THE OBJECT.

THE STUDY OF LIGHT AND COLOR.

PAGE

CHAP. I. INSTRUMENTAL MEANS OF SECURING COLOR BEAMS IN AN ELEMENTARY, SIMPLE OR PURE STATE........................ 71

The separated, associated beams constitute a spectrum. Construction of spectroscope to this end, depending on dispersion. Sufficient dispersion giving purity of beam. The prism and other apparatus. Adjustments. Location of Colors. Narrow slices of the spectrum, giving pure colors, by the use of slits. Direct vision spectroscopes. Spectra by diffraction. Application of cameras to spectroscopes.

CHAP. II. SOURCES OF LIGHT.................................... 93

Various sources of light, differing in luminosity and color, are readily comparable, and they have considerable influence upon the color of objects they illuminate, which is important to remember in actual work or testing.

CHAP. III. DEMONSTRATIONS WITH THE SPECTRUM (1)........... 96

Composite white light, its separation into constituents and recombination, proving an optical illusion. Heterogeneous beams form dominant hues. Complementary colors, how constituted and how demonstrated. Minus colors.

CHAP. IV. SOURCES OF COLOR AND COLOR IN NATURE.............. 99

Colors, however occurring in nature, are *collections* of pure colors, such as those produced in the spectroscope, and possess identical properties with these. Colors in nature are, in general, formed by the action of bodies on white light.

CHAP. V. THE PRODUCTION OF COLOR BY SELECTIVE ABSORPTION..... 101

Selective absorption accounts for nearly all color in nature. Its methods and laws are demonstrable by the spectroscope. It is a subject of great importance.

CHAP. VI. DEMONSTRATIONS WITH THE SPECTRUM (2), SINGLE AND TRIPLE SLITS 105

Isolation of spectrum colors. They are seen to differ in quality, quantity and adulteration, attributes called respectively hue, luminosity and purity. These are the constants of color and are measurable. The brightness of white light is the sum of the brightness of its component rays, both visually and photographically.

DIVISION II.—THE PRINCIPLE.

THE THREE-COLOR THEORY OF COLOR VISION AND ITS PHOTOGRAPHIC PARALLEL. THE PERCEPTION OF COLOR A PHYSIOLOGICAL PHENOMENON.

CHAP. VII. CONDITIONS NECESSARY FOR CORRECT COLOR VISION.... 107

Limitations in brightness and size of Images.

PAGE

CHAP. VIII. DEMONSTRATIONS WITH THE SPECTROSCOPE (3). USE OF TRIPLE SLIT. ALL HUES COUNTERFEITED BY THREE........ 109

Three pure hues in correct measured proportions reproduce all colors, simple or complex. Composition of spectrum hues, also lightened and degraded hues. Visual identity of simple and complex colors. Suggested simplicity of visual apparatus. Simple color nomenclature.

CHAP. IX. MAXWELL'S COLOR MIXTURE CURVES. VARIATIONS OF THESE CURVES 114

Maxwell mixed *measured* amounts of color to match spectrum hues and recorded results in curves. A universal scale of abscissa. Variations in scale of ordinates. Three useful methods of forming curves.

CHAP. X. COLOR MIXTURE CURVES AND COLOR SENSATION CURVES.. 118

Color *mixture* curves, originated by Maxwell and now employed in practice, are not color *sensation* curves, an important distinction. Abney's color sensation curves. Positions of slits for most exclusive excitation. Necessity for positive signs in practical curves. Unavoidable paling in mixtures.

CHAP. XI. EXPLANATION OF SPECTRUM EXPERIMENTS ON THE THREE-COLOR THEORY. DOMINANT HUES........................ 121

Composite color beams are referable to their action on three color-seeing nerves, the stimulation of which gives dominant hues (white and color).

CHAP. XII. THE REPRODUCTION COLORS FOR PROJECTION........... 123

Their hue, luminosity and purity Necessity for compliance with correct conditions.

CHAP. XIII. SIMPLE APPARATUS FOR EXPERIMENT................. 125

Description of simple apparatus not involving pure colors. General utility of such apparatus in three-color work. Wanted, a convenient three-color tintometer.

CHAP. XIV. THE REPRODUCTION COLORS FOR PRINTING............. 127

The relationship of projection and printing colors. Starting with white paper pigments are printed which selectively transmit certain rays producing color. Examples in patches and spectrum colors. Identity of pigments whether in glass or on paper. Color ray composition of pigments. The spectrum reproduced by pigments. The color constants, hue, luminosity and purity. Defects introduced by departure from theoretical conditions. Lack of transparency, etc. Hypothetical and practical ray composition. Further research needed.

CHAP. XV. THE PHOTOGRAPHIC PARALLEL....................... 139

The employment of photography, in place of the retina of the eye, to secure permanent records of the color effects referable to three color-seeing nerves,

DIVISION III.—THE NEGATIVE.

THE EMPLOYMENT OF PHOTOGRAPHY TO MAKE THE COLOR RECORDS.

PAGE

CHAP. XVI. SELECTION OF A COLOR SENSITIVE PLATE AND TESTING ITS COLOR SENSITIVENESS.......... 141

A sensitive plate for three-color work is required to have its range of photographic activity coincident with the range of visual impressions in respect to wave length (color). Avoid separate plates. Preliminary test for color sensitiveness shows gaps. The heterogeneity of color beams in nature, and the gaps in the spectrum, make it possible and advisable to use a substitute for the spectrum in colored glasses. Abney's color sensitometer and its many uses. Fidelity of reproduction in negatives.

CHAP. XVII. COLOR SCREENS OR FILTERS.......... 147

Color filters are used to bring the action on the sensitive plate into line with the action of colors on the eye. They can only *reduce* the action of rays too energetic.

CHAP. XVIII. THE INFLUENCE OF THE ULTRA-VIOLET RAYS.......... 148

Ultra-violet, being invisible, must not act. The amount of ultra-violet passed by photographic lenses is cut off by the filters.

CHAP. XIX. THE POSITION OF COLOR FILTERS.......... 150

Discussion of positions of color filter.

CHAP. XX. METHODS OF SELECTION OF GLASS FOR FILTERS. OPTICAL REQUIREMENTS IN LENSES AND FILTERS.......... 152

Optical methods of testing surfaces for planeity and parallelism. Forms of cells for liquids. Distortions due to filters and lenses. Importance of register. Tests for size and register.

CHAP. XXI. THE MANUFACTURE OF COLOR FILTERS.......... 157

Wet and dry filters. Vehicles. Dyes.

CHAP. XXII. SELECTING COLOR SENSITIVE PLATES AND COLOR FILTERS TO SECURE, WHEN PHOTOGRAPHING THE SPECTRUM, DENSITY PATCHES CORRESPONDING TO MAXWELL'S COLOR CURVES.......... 161

Preliminary qualitative test by spectrum followed by a quantitative test by Abney's three-color sensitometer. Adjustment of filters by the aid of this instrument. Other methods.

CHAP. XXIII. THE RELATIVE EXPOSURES.......... 166

Simple convention with regard to relation of reproduction colors makes finding the relative exposures easy. Finding exposures practically.

CHAP. XXIV. THE NECESSITY FOR USING ONE KIND OF PLATE.......... 169

Differences in gradation—characteristics of different plates. Influence of development. Its effect on the three images. Dark-room light filters. Backing plates.

DIVISION IV.—THE PRINT.

VARIOUS MEANS OF UTILIZING THE COLOR RECORD NEGATIVES TO PRODUCE THE FINAL RESULT IN COLORS.

PAGE

CHAP. XXV. THE KROMSKOP AND PROJECTION LANTERN........... 175

The principles of working. Two forms of instrument. Lantern for triple-color projection.

CHAP. XXVI. APPARATUS FOR MAKING THE COLOR RECORD NEGATIVES FOR THE KROMSKOP AND PROJECTION LANTERN............... 182

The three images taken simultaneously on one plate by the same lens. The multiple back for consecutive negatives. Another form for simultaneously taking the negatives on different plates. The development of Kromskop negatives and transparencies.

CHAP. XXVII. DR. JOLY'S PROCESS OF THREE-COLOR PHOTOGRAPHY.. 186

Taking Screens. Viewing Screens. Simplicity of the process. Means for correction.

CHAP. XXVIII. TRIPLE SUPERPOSED POSITIVES.................. 188

Three bichromated gelatine films supported on flexible celluloid are printed under the record negative, cut apart, and dyed and mounted in superposition.

CHAP. XXIX. THE DIFFRACTION PROCESS OF COLOR PHOTOGRAPHY (PROFESSOR WOOD'S) 193

Simple description of the process. Details of practical work by Professor Wood.

CHAP. XXX. THREE-COLOR TYPOGRAPHIC PRINTING............... 200

Three-color record negatives are taken as usual. From these positives are made which are copied to make screen negatives, from which blocks are printed. The blocks are printed in superposition. A variation of this process is to make the color record and screen negative at one operation.

APPENDIX I 205

APPENDIX II 207

PREFACE.

The following account of three-color photography has been compiled from a collection of lecture notes prepared for the students of my classes at the Polytechnic in this subject.

In lectures to a class no previous knowledge of the subject must be taken for granted, and it is necessary to start from the fundamental truths underlying the work; again, in order that students may have a practical and useful knowledge of the subject, every object mentioned should be shown, and every operation described should also be experimentally demonstrated. A student, under these circumstances, soon appreciates the practical points on which the argument rests and can apply the argument to his further needs in practical work, and, while he is being convinced of the truth of the argument, he is also brought into practical acquaintance with the work.

Consequently I have thought it would be more useful to leave this account in the original form than to alter it. The subject is therefore presented in such an order that the reader may work through the demonstrations and experiments and thus by degrees make himself familiar with the subject. With this object I have attempted to explain all the phenomena met with by well-known principles, and to indicate how the experiments may be readily performed by simple apparatus.

I regard it as of the greatest importance in class teaching that students should be given working hypotheses to enable them to explain (in their own minds) the phenomena, and to show materials and examples and to work simple experiments with simple apparatus. With this idea I have endeavored to state the correct principles upon which the success of the work must depend. There are at present some practical limitations to the complete following of the theory; nevertheless the correct principles should not be lost sight of, and consequently the principles are given, not as founded on the imperfect practice, but on the correct theoretical basis.

I have in the following pages drawn very freely upon the published writings of Sir W. de W. Abney, K.C.B., D.C.L., F.R.S., and Mr. F. E. Ives, to whose researches the book may be said to owe its existence. To the former we owe a great debt for his researches in color, the utility of which is largely due to their being entirely founded on quantitative measurements.

I have been encouraged to lay stress on the necessity for quantitative work by the fact that recently several firms and private workers have relinquished empirical for the more exact and more expeditious methods involving measurements. Indeed, it would seem that quantitative results are imperative on account of the accuracy with which every operation, every filter, every sensitive plate, ink, etc., must be related together to secure a correct final result. To have any value in a commercial sense the process must be expeditious and exact; it is necessary, therefore, that the conditions of working should be suitably established before commencing actual work.

Without disregarding or discounting the work of previous experiments, I think that we owe the principles and methods of three-color photography now employed to Mr. Ives, who, by his experimental ability and insistence on following correct principles, has raised three-color photography from a scientific curiosity to a position of commercial application and importance.

A book of 200 pages can by no means be regarded as giving a complete account of three-color work. It is hoped that the more important parts have been included. There is one chapter that is necessarily incomplete; it is the chapter on The Reproduction Colors for Printing. That the color ray compositions of the pigmentary printing colors could not be definitely stated was, no doubt, known to Mr. Ives in 1890, when he gave his opinions of what they should be. Since then it has been taken for granted, on insufficient proof, that the dominant hues of the printing pigments are the complementary colors of the three fundamental sensation colors respectively. As a first approximation to the truth this idea has been followed. Meanwhile, it is hoped that further researches will help to clear up this most important point.

The greater part of the information on the subject is contained in books and magazine articles. Below are mentioned the works, by the two authors referred to, dealing with the subject, together with some others which it is advisable that the students should refer to.

To make this work complete would necessitate the inclusion of text-books on several subjects, photographic, spectroscopic, and works on color generally, but this would unduly increase the size of the book.

WORKS ON COLOR, COLOR PHOTOGRAPHY, AND LIGHT.

Works by Sir W. de W. Abney, K.C.B., D.C.L., F.R.S.

Color Vision. Sampson Low, Marston & Co.

*Color Measurement and Mixture. S.P.C.K.

Color Photometry, Parts I., II., and III. Philosophical Transactions of the Royal Society, Vols. 177, 179, and 183. 1888-1892.

The Color Sensations in Terms of Luminosity. Philosophical Transactions of the Royal Society, Vol. 193. 1899.

The Scientific Requirements of Color Photography (pamphlet). Henry Frowde.

Cantor lecture on Light and Color, 1888. Society of Arts.

Action of Light in Photography. Sampson Low, Marston & Co.

Articles	Three-color photography.	Photography	No. 488 vol. x
	"	"	No. 492 vol. x
	"	"	No. 496 vol. x
	Pigments for color printing	"	No. 484 vol. x

Works by Frederick E. Ives, Esq.

Kromskop Color Photography. The Photochromoscope Syndicate, Clapham Common, S. W.

The Relative Color-Sensitiveness of Ordinary and Ortho-Chromatic Plates, by F. E. Ives. The Photographic Journal, Vol. xx., No. 8.

A Practical Demonstration of Color-Screen making and testing, by F. E. Ives. The Photographic Journal, Vol. xxi., No. 2.

Photography in the Colors of Nature. The British Journal of Photography, 1891.

Composite Heliochromy. (From the Journal of the Society of Arts.) British Journal of Photography, 1892.

* Those works marked by an asterisk are very necessary to the beginning of a study of the subject. The lectures and articles also are invaluable.

Composite Heliochromy. Journal of the Society of Arts, May 19, 1893, Vol. xli., No. 2113.

Composite Heliochromy by Three-Color Printing. The Journal of the Camera Club, Vol. viii., No. 95.

The Photochromoscope. Society of Arts, April 22, 1896, and reproduced in "Kromskop Color Photography" (see above).

Color. A text-book of Modern Chromatics, by Ogden N. Rood. Kegan Paul, Trench, Trübner & Co.

*Color. An Elementary Manual, by A. H. Church. Cassell & Co.

*Photo-Trichromatic Printing, by C. G. Zander. Raithby, Lawrence & Co., Leicester.

*The Spectroscope, by Richard A. Proctor, S.P.C.K.

Die Dreifarben-Photographie. By A. Frieherr von Hübl. (German.)

La Triplice Photographie. Du Hauron. (French.)

Works on Photography, Photomechanical Printing, Light, Optics, Spectroscopy. These may be referred to at the Patent Office Library, Chancery Lane.

INTRODUCTORY.

In the reproduction of objects in colors by the three-color method, photography is employed by reason of its peculiar property of recording exactly, rapidly, and automatically. In this method no new photographic processes are employed, and any one capable of performing the ordinary photographic operations of negative and print making can, with sufficient color knowledge, make three-color photographs.

The nature of the work, however, necessitates the photographic operations being made with great exactness; in fact, greater than is required in monochrome rendering.

The photographic worker is entering on new ground in the subject of color photography, and the introduction of the subject of color at first constitutes a difficulty. It is, therefore, necessary to pay considerable attention to the study of color before attempting to utilize our photographic knowledge.

We will commence with a brief outline of the process and its branches before proceeding to discuss the details. The student will thereby be better able to understand the connection between the several parts of the subject.

The Genesis of Three-Color Photography. Professor Clerk-Maxwell.

The three-color process of color photography is the outcome of the application of photography to the theory of color vision proposed by Dr. Thomas Young. According to this theory vision is trichromatic, and the fact that most hues could be imitated by three pigments strengthened it. This theory was subsequently amplified by Professor Helmholtz. Professor Clerk-Maxwell supported it and made careful quantitative experiments. These proved that all the spectrum colors and therefore all colors could be imitated by *three simple spectrum rays* or reproduction colors. These experiments, besides being of fundamental importance in the theory of color, are absolutely necessary in color photography. Maxwell attempted to apply photography to the representation of color, reproducing the colors of ribbons by triple projection in primary colors on the lantern screen. On May 17, 1861, Maxwell delivered a lecture at the Royal Institution from which the following is abstracted:

"Experiments on the prismatic spectrum show that all the colors

of the spectrum and all the colors in nature are equivalent to mixtures of three colors of the spectrum itself, namely, red, green (near the line E), and blue (near the line G).

"The speaker assuming red, green, and blue as primary colors, then exhibited them on a screen by means of three magic-lanterns, before which were three glass troughs containing respectively sulphocyanide of iron, chloride of copper, and ammoniated copper.

"A triangle was thus illuminated, so that the pure colors appeared at its angles, while the rest of the triangle contained the various mixtures of the colors, as in Young's triangle of color.

"The graduated intensity of the primary colors in different parts of the spectrum was exhibited by the colored images, which, when superposed on the screen, gave an artificial representation of the spectrum.

"Three photographs of a colored ribbon taken through the three colored solutions respectively were introduced into the lantern, giving images representing the red, the green, and the blue parts separately, as they would be seen by Young's three sets of nerves separately. When these were superposed a colored image was seen which, if the red and green images had been as fully photographed as the blue, would have been a truly colored image of the ribbon. By finding photographic materials more sensitive to the less refrangible rays, the representation of the colors of objects might be greatly improved."

The plates in use in Maxwell's time were not sensitive below the blue, and the red and green ribbons were photographed by the blue and violet rays which they reflected and which were passed by the screens. In 1873 Professor Vogel announced that dyes would influence the distribution of color sensitiveness in plates, a discovery which has led to important results.

In the experiments of Maxwell we have the basis and commencement of all subsequent work.

The work of Mr. Ives.

To Mr. Ives is due the completion of the theory. He pointed out what should be the reproduction colors, and what rays should pass through the color filters used in photographing. He devised cameras to take the three images through color filters simultaneously, and an instrument to show the pictures in colors. He made triple prints both in the form of transparencies and on paper by photomechanical means and showed what the colors of these reproduction pigments should be. The outcome of his work is the Kromskop system, by which the color images are made and viewed and in which a high degree of truth in the color representation is secured, and also the process of photomechanical printing in three colors, which is destined to be of large commercial utility.

Ives made color record negatives of the spectrum, in which each

simple color ray affected one or two negatives to the amount indicated in Maxwell's curves. For this purpose he employed color sensitive plates and filters which recorded all those rays which affected the particular sensation nerve. To secure equality of action he made the three exposures simultaneously upon the same plate, which was afterwards developed entire. A positive transparency was printed from the negative, which was cut up and mounted on a cardboard frame to fit the Kromskop, by which instrument the final image in colors was seen.

The distinction that Ives drew between the color reproduction filters and the color selection filters is one of great importance. (See Ives' lecture Society of Arts, April 22, 1896, Kromskop Color Photography.)

A modification of the process has been made by Dr. Joly, of Dublin, and is described in Chap. xxvii.

Quite recently (1899) a modification has been introduced by Professor Wood, of the University of Wisconsin, U. S. A., which depends upon diffraction for the reproduction colors (see Chap. xxix.).

The subject is conveniently arranged in four divisions.

1. The study of light and color (the object).

2. The three-color theory of color vision and its photographic parallel (the principle).

3. The employment of photography to make the color records (the negative).

4. Various means of utilizing the color record negatives to produce the final result in colors (the positive).

DIVISION I.

THE OBJECT.

THE STUDY OF LIGHT AND COLOR.

CHAPTER I.

INSTRUMENTAL MEANS.

When we wish to study a thing it is first necessary to isolate it. To study color, therefore, it is necessary to find a source of color and then to isolate its constituent beams into the most elementary or primary condition. The most convenient source of color is white light, and there are many means of isolating its constituent color beams (see Color in Nature, p. 99), the most convenient of which are by dispersion and diffraction.* The necessary instrumental means constitutes a spectroscope.

This chapter is devoted to the subject of the spectroscope, the principles on which its action depends, and the necessary points to be looked to in constructing an apparatus for photographic purposes.

A beam of white light passed through a spectroscope emerges as a broad fan-like collection of colored beams, in which all the con-

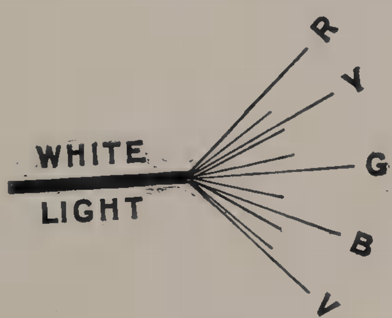

Fig. 1. Separation of Constituent Beams of White Light.

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* The simplest means for securing isolated beams of light is by selective absorption (see p. 101).

stituent rays are separated. It should be particularly noted that this is the sole function of the instrument, the beams being changed in no other particular. This is represented in the figure. (Fig. 1.)

It is with the beams thus reduced to an elementary condition that our experiments are to be performed.

Requirements in a Spectroscope.

The first requirement in a spectroscope is that it should be suited to the particular work it is required to do. It is, therefore, advisable to consider to what purposes it is to be put before purchasing or constructing one.

Now, spectroscopes are generally made for the purpose of mapping lines, which is done either by the eye or by photography. Every other consideration is sacrificed to the clear delineation of the lines and to the means of determining the position of these lines. The dispersion and definition required mean great perfection of the optical work, and the arrangements for measuring involve accurate mechanical work. The instrument is therefore expensive if well constructed.

A spectroscope is generally employed in three-color work to photograph bands of colored light. The bands need be of only approximate purity; that is, a slight overlapping of *adjacent* colors is not detrimental. Definition is, therefore, not of primary importance.* The bands should be free from scattered light; blue light (say) should not be scattered over the other part of the spectrum. The whole length of the visible spectrum should be in approximate focus in the same plane, and this plane preferably at right angles to the lens.** All delicate parts should be protected from injury and the whole protected from dust. There should be no moving parts to get disarranged, and the instrument should be ready for work at any instant without requiring adjustment, to secure which every part of the instrument should be rigidly fixed on a strong base-board, together with the electric or other lamp, and its condensers. The plate-holder should allow of several spectra being taken on the same plate.

The principles of action of the spectroscope. Refraction.

It is possible that students may prefer to make their own photographic spectroscopes, to do which it is necessary to know the leading principles, which are set out in the following pages.

* High dispersion is also not required, therefore one prism only need be used for purely photographic purposes. The necessary length of spectrum is obtained by a camera lens of long focal length. The student should distinguish between dispersion and size of spectrum. (Increased dispersion is the further *separation* of the spectrum colors. Increased size of spectrum, due to further magnification, increases both the length and width.)

** In the spectroscope illustrated in Fig. 15 the plane of the spectrum is exactly at right angles to the mean direction of the rays.

When a beam of light of one color falls on the surface of a transparent medium, such as glass, at an angle to the surface, the rays traverse the glass in a different direction; they are refracted, and when entering an optically denser medium (as from air into glass) the bending is always towards the normal, or perpendicular to the surface. (Fig. 2.) The image of a stick half in water

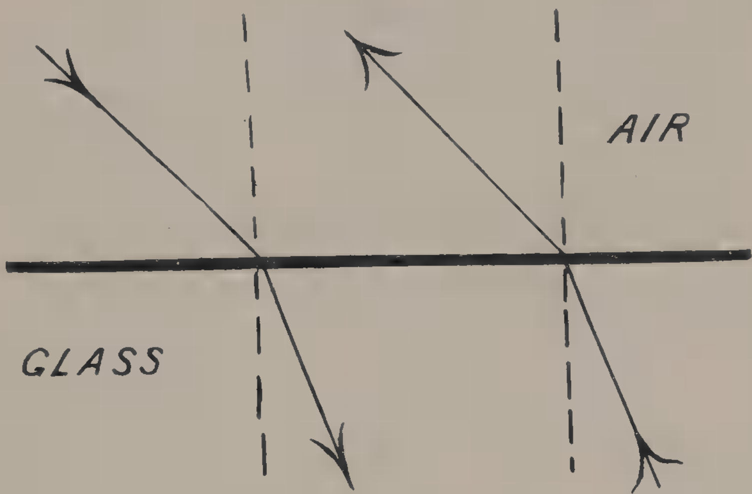

Fig. 2. Refraction.

appears bent, and an ink-spot on paper covered by a piece of thick glass appears moved from its position. (Fig. 3.) If the second

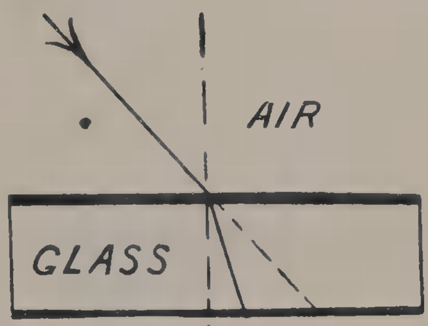

Fig. 3. Displacement of Ink-spot.

surface of the glass is parallel to the first, the ray emerging from the second surface is parallel to the original direction and no alteration of direction takes place, but only a slight lateral displacement, depending on the thickness of the glass, the inclination of the rays, etc. (compare with the parallel glass troughs used for color filters). (Fig. 4.)

If the second surface is inclined to the first the ray suffers two refractions, and is always bent away from the angle that the two surfaces enclose. (Fig. 5.)

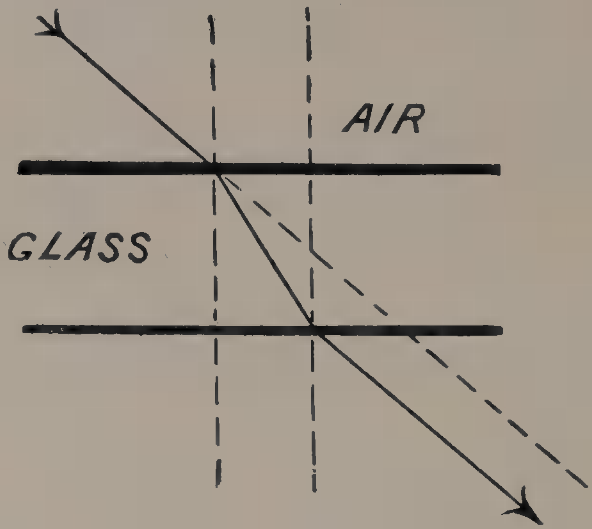

Fig. 4. Refraction through Parallel Plate.

The amount of bending at a surface is dependent on the particular color of the light operated upon, the refractive power of the

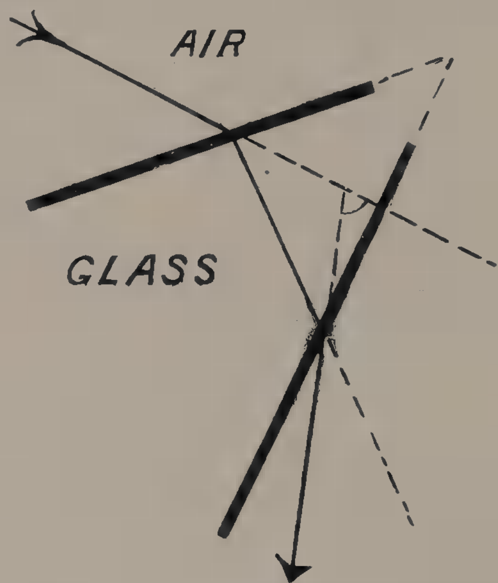

Fig. 5. Refraction through Prism.

medium, and the angle at which the ray falls on the surface. In the case of a second surface the angle of incidence at the second surface will depend on the inclination of the two surfaces.

Now, a beam of white light contains various colored beams, and the bodies which they traverse will have different effects upon them. When, therefore, a beam of white light falls on the surface of a medium, such as glass, the original beam is split up into colored

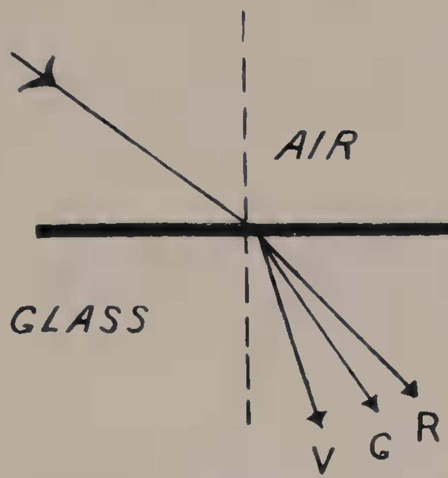

Fig. 6. Dispersion at surface.

beams each of which has a different direction to the original beam (Fig. 6). To make the experiment, take a piece of black paper and

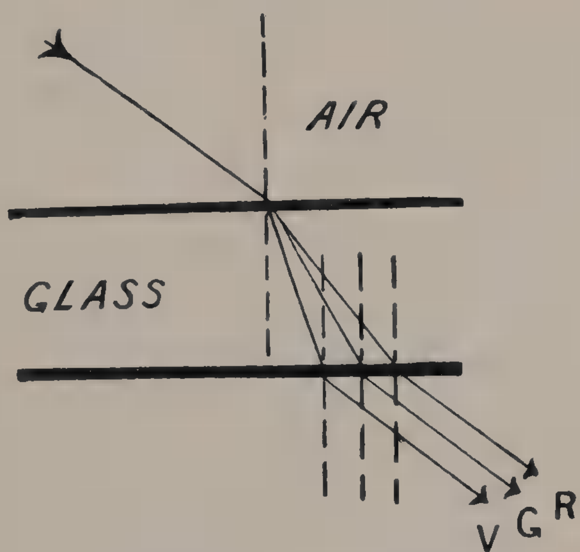

Fig. 7. Dispersion by parallel plate.

cut a very narrow slit in it, and float it upon the surface of water in a white pudding basin in the sunlight; the light passing through the slit forms a spectrum on the bottom of the basin. Also, an object lying at the bottom of a bath can be seen fringed with color by apply-

ing the eye near the surface. If the second surface be parallel to the first, the rays will be rendered parallel to their former direction. (Fig. 7, and compare Fig. 4.)

If the second surface of the glass is at an angle to the first the dispersion takes place at both surfaces and is increased. It should be noticed that the dispersion of the rays is always accompanied by a general bending of the colored beam. Dispersion is really the difference between the total bending of the extreme color rays, red and violet. (Fig. 8.)

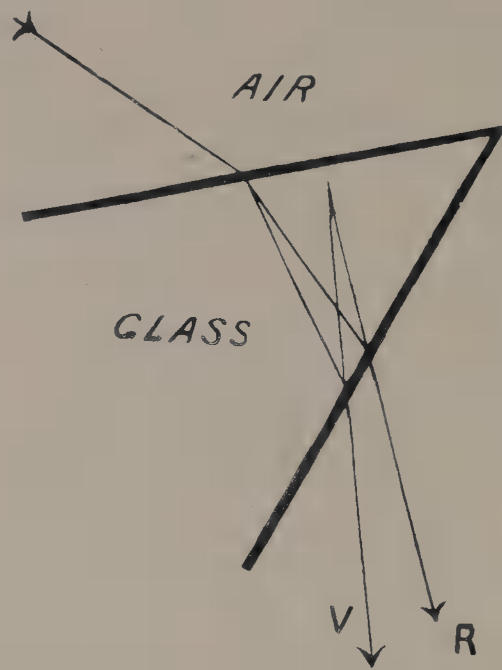

Fig. 8. Dispersion by prism.

Impurity. Use of Lenses and Slit.

It will have been noticed that the spectra produced by these rough means are very imperfect. There is a whiteness in the centre of the colored beams due to overlapping spectra. The explanation of this is seen in Fig. 9, where are represented the two outside and the centre beams of a ray of sunlight. The beams are dispersed at the first surface and the spectra are cast on the sheet of white paper in contact with the second surface (or it may be the bottom of the basin in the experiment instanced before). The color beams overlap, and, where sufficient beams meet, give white light, which is seen in the interior portion of the beam (see page 45).

The edges, where no white is formed by overlapping, are colored, one red, the other blue. (See also Fig. 9a and Fig. 11.)

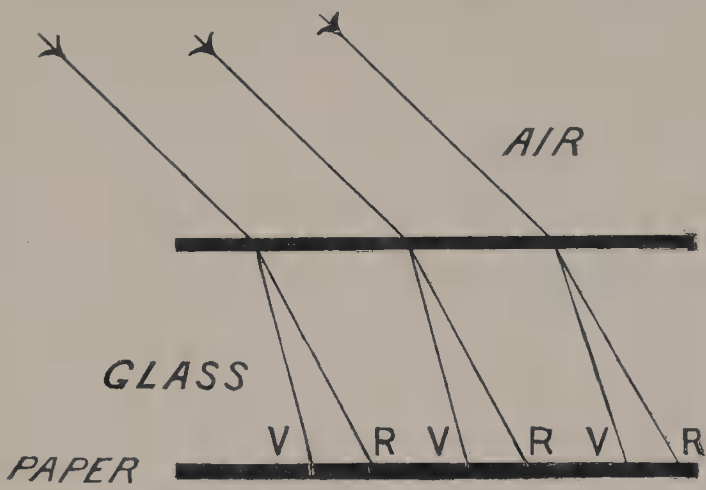

Fig. 9. Overlapping spectra.

To avoid this mingling of rays and to secure a pure spectrum, either an infinitely slender beam (parallel, such as sunlight) must

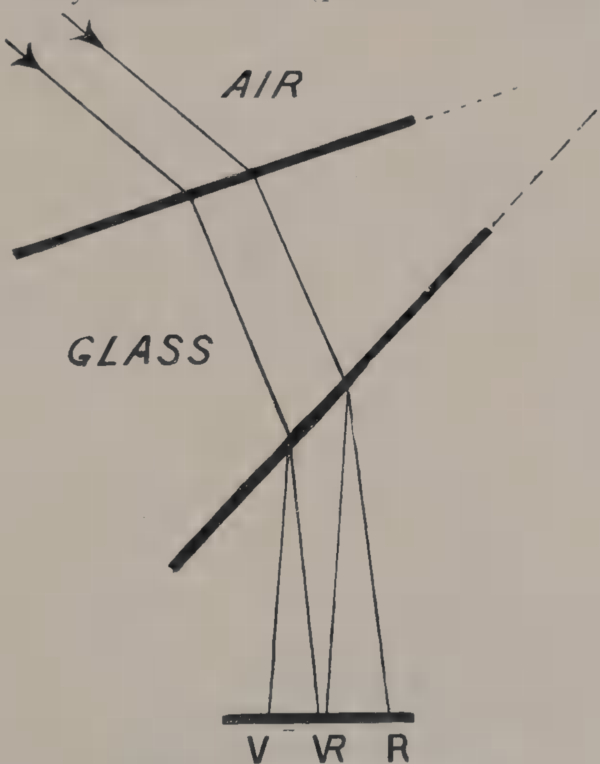

Fig. 9a. Overlapping spectra.

be used, in which case there will be very little light, or a lens to sort out the colored beams and bring them each to a focus. Thus the

lens of the eye may be used to receive the rays direct from the prism, or a lens may be used to focus the rays upon a screen. In either case a spectrum is produced in which each color is represented by

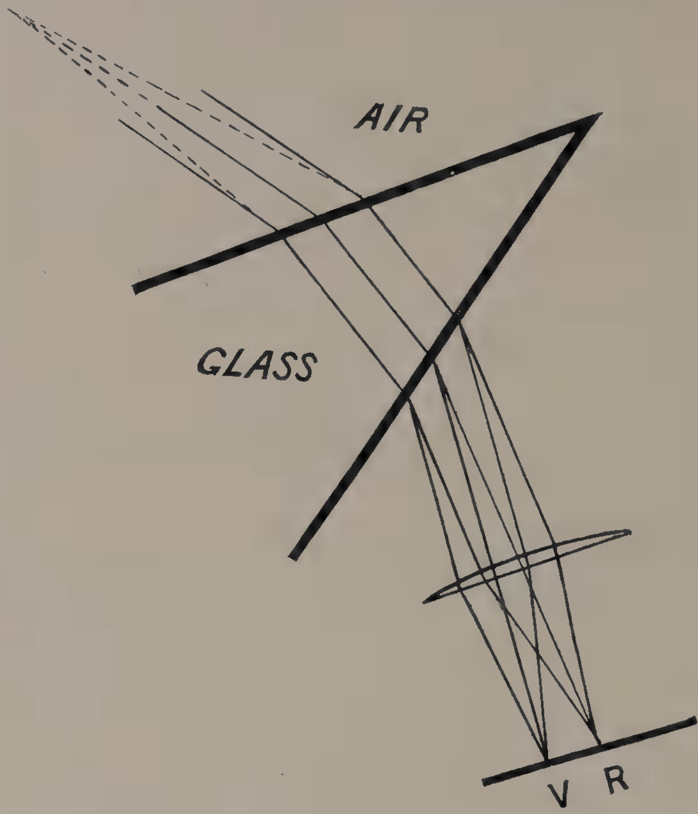

Fig. 10. *Production of pure spectrum.

colored images of the sun. There will thus be still a little impurity on account of the images having appreciable size. (Fig. 10 and Fig. 11.)

Fig. 11. Overlapping images.

If the rays diverge from a slit, and a lens is used to focus them before or after passing through the prism, the images are dependent on the width of slit, which can be made as narrow as desired. (Fig. 12.) Such an arrangement will give a pure spectrum. It is preferable also to use a lens behind the slit, and at the right distance

* Figs. 9a and 10. These diagrams are not quite correctly drawn; the dispersion originates at the first surface. The same applies to Fig. 14.

to form parallel rays, which fall on the prism.* The emergent color beams issue parallel and are received by a lens which brings them

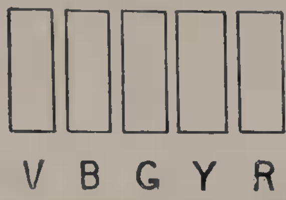

Fig. 12. Images of slit.

all severally to a focus at its principal focus. This telescope or camera lens (as it is called) forms images of the slit in color.

Source of Light.

To secure a sufficiently bright spectrum a flame can be brought close to the slit, or a lens may be used to focus the flame upon it. (Fig. 13.) This is especially useful when sunlight is used, though on account of the apparent movement of the sun a heliostat is required. (See Abney, Photographic News, Vol. 21, article Photo-spectroscopy. Also Light, by Mayer and Barnard, Nature Series, Macmillan.)

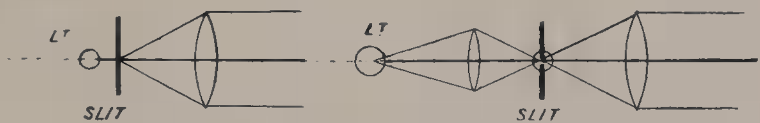

Fig. 13. Illuminating arrangements.

The whole arrangement will then be as shown in plan, Fig. 14, and in the photographs, Figs. 15 and 16.

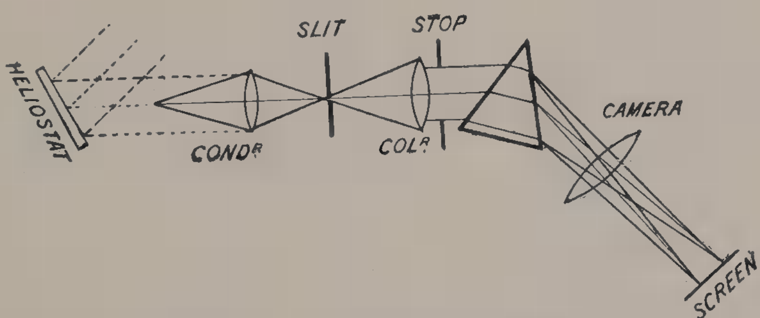

Fig. 14. General arrangement.

The dotted rays represent parallel rays from the sun reflected

* The reader is supposed to have access to some book on the spectroscope, such as Proctor's, or Physical Optics, Glazebrook, Chap. viii., Longmans, Green & Co.

from a heliostat mirror and received by a lens forming an image of the sun on the slit (a lens of 10½ inch focus forms an image of the sun 3/32" diameter). Instead of the sun's rays a lamp, or gas or other light may be used near the slit (electric light requires a lens on account of the heat). The rays, after passing the slit, fall on the collimating lens and are rendered parallel, and then fall upon the prism or prisms. The beams of the same color suffer equal refraction and emerge parallel, when they are received by the camera lens, which brings them (or rather the colored images of the slit) to a focus.

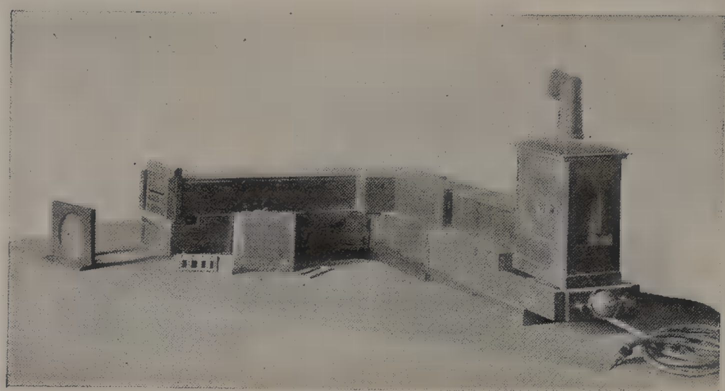

Fig. 15. Photospectroscope, complete with electric lantern and condensers. The dark slide for several exposures, the triple slit, and the large combining lens are also shown.

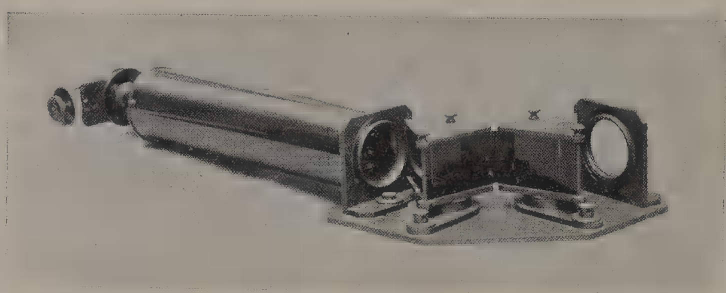

Fig. 16. Arrangement of prisms, collimator, slit, and lenses of Photospectroscope.

Construction of the Spectroscope.

The Prism.

In the construction of such an apparatus the first requirement is a prism. Upon the character of the work depends the material of which the prism is to be made. Glass is opaque to ultra-violet light a little beyond the visible spectrum, whereas Iceland spar and quartz are very transparent. If it be desired to investigate very far

into the ultra-violet, then quartz prisms, condensers and lenses and color cells should be used, otherwise an Iceland spar prism and quartz lenses will give a sufficiently large amount of ultra-violet. For ordinary purposes colorless flint glass of medium density should be used. The glass should be tested for color over white paper. The refracting angle may be from 60° to 62°. Only the two faces are polished, the remaining sides are left ground. Upon the size of the prism or rather the height (equal length of edge A) depends the size of the lenses. (Fig. 17.) The height and size of the

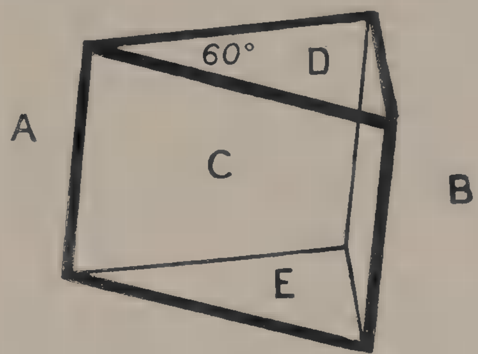

Fig. 17. Prism.

prism should be governed by the requirements. If a bright beam of light is required for visual experiments, then the prism and lenses must be large; if only required for photographic work and private observation, then a smaller prism and lenses can be used. (The prisms shown in the photograph, Fig. 16, are 2¼" height and 3½" length of face.) A size from one inch upwards would be suitable.

The three sides of the prism not used should be backed with some black material of the same refractive index as the glass; this is to absorb any scattered light. This can be told when the ground surface disappears when looking through a face. Bitumen dissolved in benzene forms a very suitable mixture. The writer found that an etching ground (black) as used by artists was perfect for the purpose.

The Lenses.

If a prism of 1" height is chosen, lenses of 1½" diameter will be sufficient for the camera lens and collimator. These may be plain or achromatic, as desired. When uncorrected lenses are used for the collimator, the length between slit and lens is not correct for rays of all colors, and so some rays emerge parallel, others converging and others diverging. If the camera lens is not achromatic, there is a greater difference between the distances at which the red and blue images are produced, necessitating the plate being inclined

to the general direction of the rays. The collimating lens should be about 10″ focus. The exact length is immaterial for the purpose, though on the relative focal lengths of the collimator and camera lenses depends the relation between the length of slit and height of spectrum.

Length of Spectrum.

The focal length of the camera lens will be dependent on the length of spectrum required.

The length of spectrum obtainable from red to violet (visible in daylight) will be dependent on several factors.

1st. The dispersive power of the prism.

2d. The angle of the prism.

3d. The angle which the incident rays make with the first surface.

4th. The focal length of the telescope or camera lens.

5th. The inclination of the surface on which the rays are focussed to the axis of the camera lens.

The dispersive power of the prism.

If the angle between the red and violet rays (visible by daylight) is known, then the length of spectrum can be calculated for a certain focal length of the camera lens.

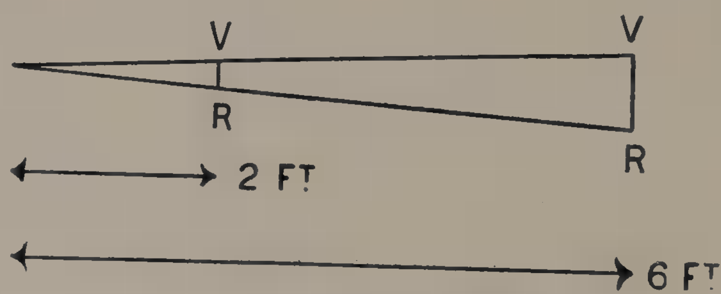

Fig. 18. Focal length and size of image.

The diagram (Fig. 18) will illustrate this: Suppose the angle $3°$ and the camera lens 2 ft. focus, then multiplying the focal length in inches by .0524 will give the length of spectrum in inches (at right angles to the axis of lens) $24 \times .0524 = 1.2576$ or $1\frac{1}{4}$ inches. for a six-foot lens $72 \times .0524 = 3.7728$ or $3\frac{3}{4}$ inches.

The angle of the prism may be about 60°. The dispersion increases with the angle.

The position of the prism with reference to the incident rays will alter the length of the spectrum.

The position generally chosen is such that the mean refracted rays (the green, say at E, Fraunhofer line) and the incident rays

make equal angles on each side of the prism (see minimum deviation, Fig. 19). Roughly speaking, the spectrum is, in this position, at its shortest dimensions.

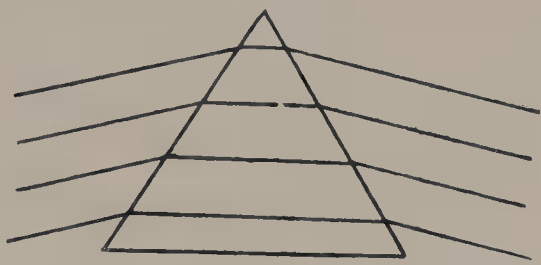

Fig. 19. Position of minimum deviation.

The length of spectrum is directly proportional to the focal length of the camera lens. (Fig. 18; see above, Dispersive Power of the Prism.)

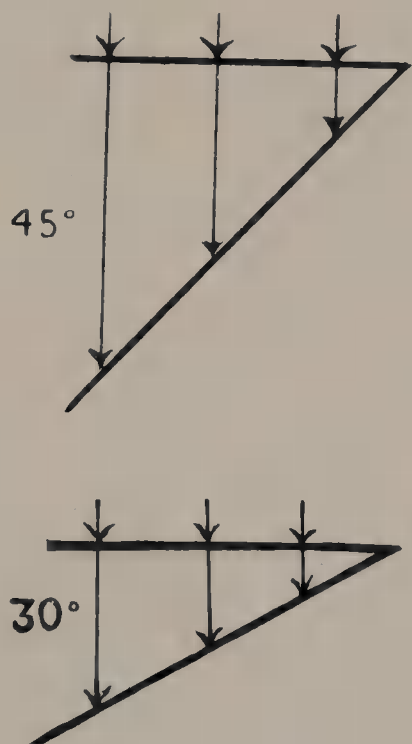

Fig. 20. Effect of angle of plate.

The inclination of the plate to the rays may cause the spectrum to be from a minimum to an infinite length. Thus if the spectrum is 2″ long when square to the axis of lens, at 30° it will be 2.3″ and at 45° inclination 2.8″. (Fig. 20.) Allowance must be made for this according to whether single lenses or achromats are used.

The Slit.

A wooden tub is next required, having at one end the collimating lens and at the other the slit. The cheapest form of slit is one in which one jaw is fixed and the other jaw made to move parallel to the first, the distance between the two being adjustable by a screw. (Fig. 21.)

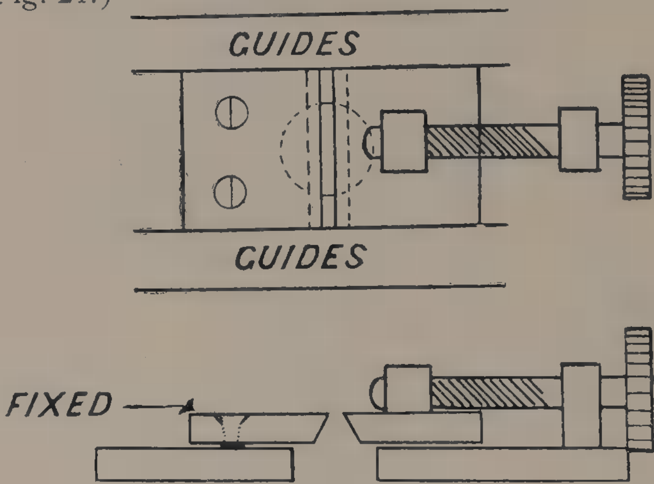

Fig. 21. Slit.

The slit fitting is now fixed at one end of the tube and the collimating lens at the other, the former capable of a slight movement in the direction of the axis to enable it to be moved into such a position as to give parallel rays (focussing).*

Adjusting the Collimator.

One method to secure this is to place a piece of ground glass against the jaws of the slit and to focus a distant object, such as a church spire, by moving the lens until exactly in focus; or a magnifier (previously focussed on the slit) may be used to examine the aerial image of the distant object.

Another method, simpler, easier, and better, is to use a telescope previously focussed on a very distant object. Place the collimator on a holder with a piece of ground glass close to the slit and illuminate by a bright light. Then examine, with the focussed telescope, the image of the slit through the collimating lens, and, without disturbing the focus of the telescope, move the collimating lens until the slit is seen perfectly sharply. If desired, a piece of green glass can be used outside the slit to give approximately monochromatic green rays (see also page 152).

The remaining parts.

Next, the lens to form the camera image is placed at the end

* Those who wish to construct a slit for themselves should refer to Mr. Shepherd's paper on "The Scientific Translation of Color into Monochrome." *The Photographic Journal,* July, 1898, vol. xxii., No. ii.

of another short movable tube which enters into a large wooden tube of oblong section which forms the camera.

The prism must be placed on a support capable of movement.

Assembling and Adjustment. Minimum Deviation and Focussing.

Next assemble the parts and produce a spectrum on a piece of ground glass inserted into the camera tube. Arrange the three pieces of apparatus so that a spectrum is thrown on the centre of the ground glass, and proceed to adjust the angle of incidence for minimum deviation.

Illuminate the slit by a bunsen flame burning blue and surrounded by a ring of wire round which asbestos fibre is twisted and which has been soaked in a solution of common salt or washing soda. Place the prism about 1″ from the collimating and camera lenses, and focus the yellow line of light seen. Then rotate the prism slightly in either sense, when the ray will be found to move also. A position will eventually be found where the yellow line is least deflected from its original direction. (Refer to a book on spectroscopy or Glazebrook's "Physical Optics" or "Practical Physics.")

This singular position is known as the position of minimum deviation, and, though not necessary to correct performance when parallel rays are used, it serves as a guide to replace the prism in its former position after removal. In this position the rays make equal angles with the faces on entering and leaving. (Figs. 19 and 22; see also page 89.)

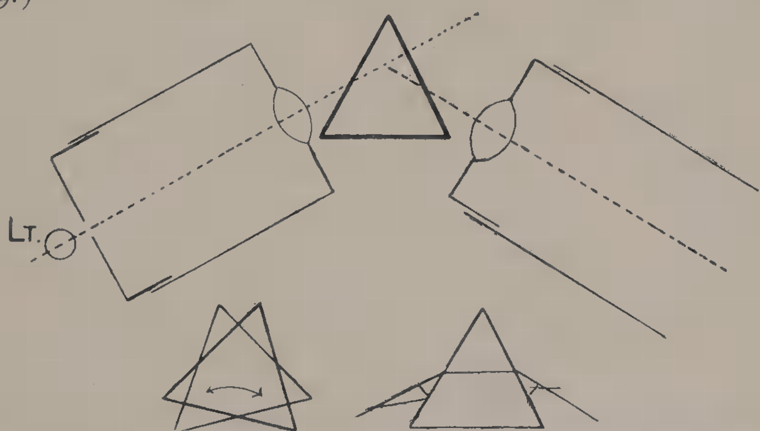

Fig. 22. Adjustments of collimator lens, camera lens, and prism.

Next a piece of burning magnesium ribbon can be used to give some noticeable bright lines in the green and the position of minimum deviation for these rays found. The whole of the daylight, or preferably (visible) electric light spectrum, should be previously arranged on the ground glass by moving the camera tube and lens.

Next a wire and asbestos ring soaked in a mixed solution of sodium, potassium, lithium, calcium, and strontium salts should be

put in the blue bunsen flame, and the various bright lines focussed on the ground glass, the screen being angled as may be necessary.

This position having been found, means must be provided to take a dark slide holding a ¼ plate or a ½ plate either horizontally or vertically, according to the length of spectrum. At the end of the camera is a board with a slit about ½" wide and of the length of the spectrum, and against this is the dark slide working in grooves and so arranged that successive exposures may be made on the same plate. A ground glass can be used in the dark slide when required. If it is required to use other prisms, arrangements must be made to alter the angle of the back of the camera.

The two wooden tubes should be fixed on a board, and, if required to move to suit the use of various prisms, each should have a pivot at the lens end and near the face of the prism. A box should be made to enclose the prism and the ends of the two tubes to prevent the entrance of light. (See photograph, Fig. 15.)

A shutter can be fixed close behind the slit. A piece of wood with a wire running through it forms a convenient door, and the wire can be turned over at right angles outside to make a handle.

For artificial light a condenser is required, and the whole spectroscope, including condenser and electric light (if needed), should be upon one base. For use by daylight the whole instrument may point to the sky, or sunlight may be reflected into it by a heliostat.

Prevention of Scattered Light.

Before being finally put together, the whole of the interior of the instrument should be blacked with a dead black paint (composed of drop black ground in turpentine, mixed with gold size and turpentine), and diaphragms should be inserted in the camera and collimator tubes to prevent stray light reaching the plate. The box enclosing the prism and the two tubes should be of *ample size,* and, it will be unnecessary to add, capable of passing the spectrum without obstruction.

For photographic work the beam of light from the collimating lens should be smaller than the prisms, so that it may pass through without obstruction and consequent scattering. The beam may be reduced at the collimating lens or at the condenser.

When completed, the instrument should be examined for stray light(like a camera). This is important, because a little scattered blue light (to which plates are very sensitive) is able to effect a great deal more than a lot of red light (to which plates are little sensitive). Scattered light is readily detected by taking negatives.

To avoid fog the camera and prism must be kept dusted (the principal reason why only one prism is recommended is on account of the smaller number of reflecting surfaces and the diminished scattering resulting therefrom). The prism should be large enough to receive the collimator beam, and the camera lens large enough to receive the dispersed beam.

Scaling. Permanent on Instrument.

To provide some indications of the whereabouts of the different colors some means of scaling the instrument is necessary. It will be noticed, when burning the salt in the flame, that sodium gives one very noticeable landmark, and salts of the other metals will give other noticeable lines. In this way a large number of places may be found from end to end of the spectrum. If daylight be used and the slit be sufficiently narrow, many dark lines will be noticed crossing the spectrum. These are known as Fraunhofer lines, and in many cases will agree in position with the bright lines given by the incandescent salts. A hydrogen tube worked from an induction coil is also very convenient, giving the Fraunhofer lines C F G and "h." The positions, in the spectrum, of these lines may be referred to a millimetre or other scale permanently attached to the instrument.

The position of the lines is peculiar to the particular spectroscope by which the lines were determined and to the arbitrary scale to which they were referred. It is necessary that the position of the lines, and, therefore, of the colors, should be independent of the pecul-

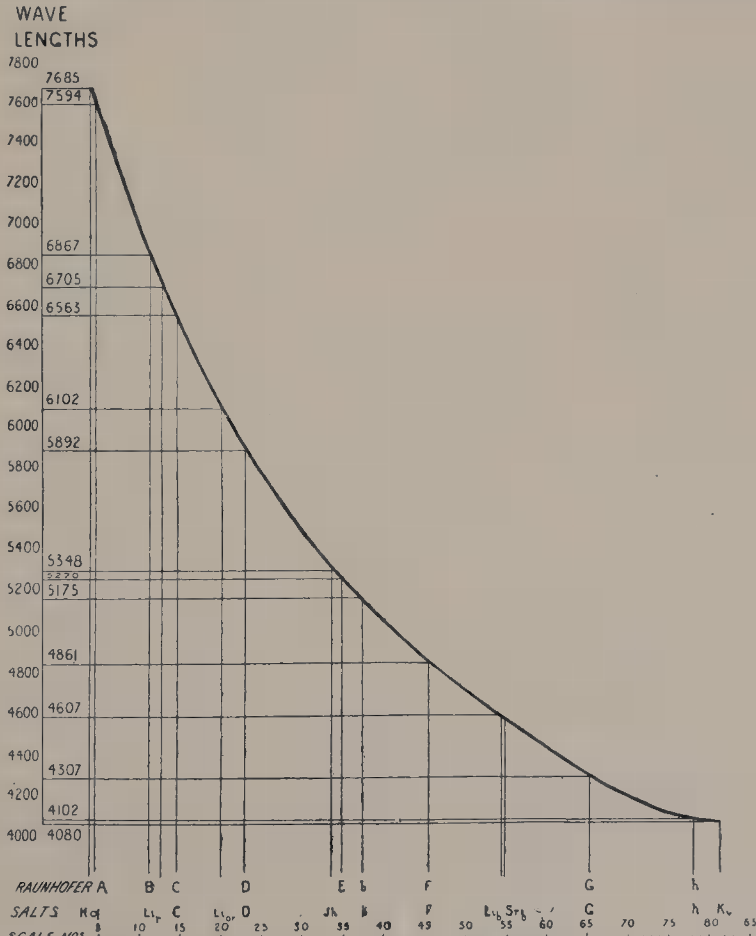

Fig. 23. "Graphed" Scale of Spectroscope.

iar construction of the instrument which involves the number and positions and refracting angles of the prisms, the relative dispersive powers of the principal sections of color, etc. If each line be mapped according to its color, or, in other words, its wave length, a scale of universal application will be formed.

The wave length of each fiducial line is plotted on squared paper against the millimetre scale of the instrument. A freehand curve is drawn through all the points; this serves to check the results and to find other lines by interpolation. The figure will show how this is done. (Fig. 23.)

Table of Wave lengths, Fraunhofer lines, etc.

Name of Line.	Color.	Salt and how volatilized.	No. on scale of spectroscope.	Wave length in tenth metres.	Frequency.	Frequency Squared.
Potassium	red	Potassium salts in bunsen	4.00	7685	..	..
A	red	Interpolated or Daylight	4.50	7594	3952	15618
B	red	Interpolated or Daylight	11.00	6867	4365	19055
Lithium	red	Lithium salts in bunsen	12.75	6705	..	..
C	red	Hydrogen tube	14.50	6563	4572	20904
Lithium	orange	Lithium salts in bunsen	20.00	6102	..	..
D	orange	Sodium salts in bunsen	23.00	5893	5091	25918
Thallium	green	Metallic Thallium in bunsen	33.50	5348	..	..
E	green	Interpolated or Daylight	35.00	5270	5692	32398
"little b"	green least refracted line. green	Metallic Magnesium in bunsen	37.50	5184	5800	33640
F	green blue	Hydrogen tube	45.50	4861	6171	38080
Lithium	blue	Lithium salts in arc	54.25	4603	..	..
Strontium	blue	Strontium salts in bunsen	54.50	4607	..	..
G	blue	Hydrogen tube	65.00	4308	6974	48497
Calcium	blue	Calcium salts in bunsen	..	4226	..	..
"little h"	blue	Hydrogen tube	77.75	4102	7313	54726
Potassium	violet	Potassium salts in bunsen	81.00	4080	..	..
H	violet	Calcium in arc	..	3969	7560	57153
K	violet	Calcium in arc	..	3934	7627	58171

The first column gives the common name of the line, the second the color in the spectrum, the third the method of production, whether it be a salt to be used in the bunsen burner or arc light, or by the hydrogen tube; the fourth column shows the position of lines on the millimetre scale of the instrument, and the fifth column gives the wave lengths in ten-millionths of a millimetre; the sixth column gives the frequency or reciprocal of the wave lengths, which is easier to plot; and the seventh column gives the frequency squared, which, when plotted, gives a practically straight line, which is consequently still easier to draw.

All the above lines can be easily secured, and sufficient lines are given by salts in the bunsen flame to furnish fiducial lines in every region of the spectrum.

Scaling. On Photographic Plate.

The above is a method of making a complete scale of the spectrum for a spectroscope, and is useful where the prism is fixed. A simpler method, and one which can be used on occasions when the prism is not placed always quite in the same position near minimum deviation, is to make a scale of a few well-known lines on a portion of the photographic plate by employing for the purpose an arc light whose poles are brushed over with a dilute solution of hydrochloric acid in which are dissolved some common salt, the chloride or carbonate of lithium, the same of magnesium and of calcium. For those who have not an arc light Abney recommends a piece of magnesium ribbon in which is wrapped some solid salts of lithium and sodium. Also these salts may be burned in a bunsen burner. For those requiring fuller instructions Sir W. Abney's paper ("The Prismatic Spectrum and its Scale," Photography, Vol. X., No. 504, page 44) should be consulted.

By employing a dark slide which is capable of moving vertically, two exposures may be made on the plate, one, say, of the material to be tested, and immediately under it another on a few datum lines, whose position with reference to the Fraunhofer lines is well known.

Triple Slit.

For the purposes of demonstration a larger spectroscope than the one described is useful—containing two prisms giving a spectrum double the length of that given by one. With a longer spectrum the apparatus described below can be conveniently used. This consists of a metal frame carrying a screw on which hang six pieces of metal whose edges are bevelled. This is fastened to a wooden frame, which takes the place of the dark slide, and is at the same distance from the camera lens as the sensitive plate is when in the dark slide. By varying the distance apart of the pieces of metal the apertures can be varied, allowing more or less broad bands of

color to be transmitted. A V-shaped groove, behind the movable leaves, is to receive pieces of card to fill up the spaces between each pair of leaves. This triple slit is a modification of one designed by Sir W. Abney. (For method of measurement of slit widths see page 110.)

Fig. 24. Triple Slit.

In the demonstrations in the next chapters we will suppose this triple slit arrangement to be used.

A large combining lens of about six inches diameter and two feet focal length is required to produce images of the first surface of the prism (see Abney's "Color Measurement and Mixture").

Modifications of Standard Form of Spectroscope. Direct Vision.

A convenient form of spectroscope, suited to many purposes, is what is called a "direct vision" spectroscope. This is exceedingly handy for both visual and photographic purposes. For the latter purpose the spectroscope requires to be fitted on the front of a camera, and then pointed to the sky. A dark slide can be used to take several spectra upon the one plate. On account of the number of prisms the scattered light in such a spectroscope is large. Its handiness for both visual and photographic purposes is, however, its sole recommendation. Its price is within the reach of every one and the fitting to a camera is easily made. The construction and general arrangement will be understood from the sketch.

The slit A is at the principal focus of the lens B, and, with the prism train C removed, would be focussed by the eye at D. The prisms disperse the colored beams without sensibly altering their general direction, and virtual, enlarged images of the slit, in every color, are seen by the eye. To produce an image on a screen or photographic plate, the lens B must be removed from the slit A until converging beams are formed having the foci in the direction of D.

By replacing the train of prisms by a grating suitably mounted (see also Fig. 25) a similar result is produced.

Quite recently Mr. Thorp, of Whitefield, near Manchester, has produced casts of diffraction gratings which are mounted on narrow angle prisms and made into direct vision spectroscopes. The dispersion in these is large and they should become of great utility.

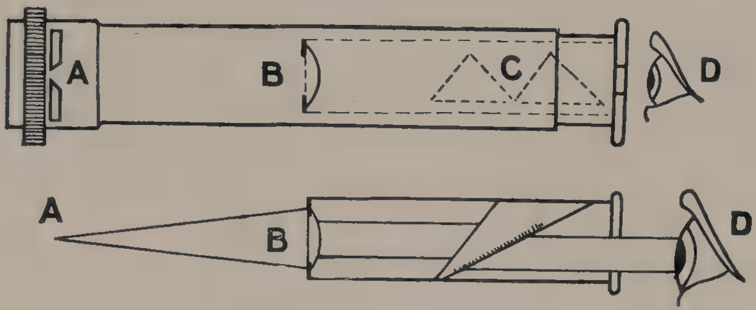

Fig. 25. Direct Vision Spectroscopes (Prismatic and Diffraction).

Instead of employing a prism for spectroscopes the same arrangements may be used with a diffraction grating. Great dispersion is gained, but on account of the grating producing several spectra much light is lost, and there is more difficulty in avoiding scattered light. There is also some overlapping of spectra of different orders, which is a drawback, especially for photographic work. Thus the red of the spectrum of one order may have superposed on it the ultra-violet of another order. This is especially noticeable when using electric arc light.

To avoid the overlapping of spectra a narrow-angle prism must be used against the grating. This causes the spectrum to be curved a little.

Gratings are of two kinds, reflexion and transmission gratings; the former are generally ruled on speculum metal, the latter on glass. Mr. Thorp makes reproductions of these latter, which are

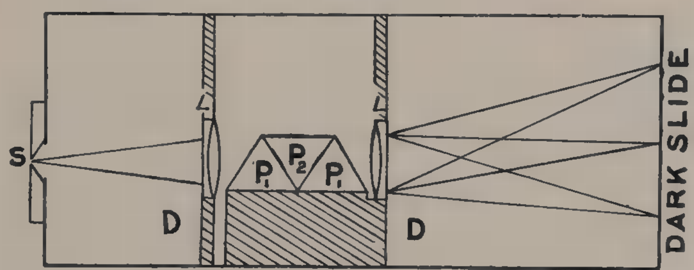

Fig. 26. Direct Vision Photo-Spectroscope. Description:—S is a slit fixed at one end of a box. L L are lenses throwing images of the slit in colors at the dark slide. P P P are the three prisms comprising the train. D D are the supports and diaphragm.

quite inexpensive, and can easily be fitted up in spectroscopes. They may take the place of the prism in the spectroscope described above or may be mounted in another form, as in the illustration (Fig. 26). This latter arrangement makes an exceedingly handy

form of spectroscope, and one which can be readily fitted up by any one. The slit can be easily made by using two pieces of printers' brass rule (which is worked to a feather edge); the lens may be a single lens or an achromat; the dispersion can be secured by either a train of prisms or a grating; the dark slide can be bought; and the woodwork to form the camera made by a carpenter.

The sketch shows the simplest form of fitting up; instead of the two achromats at L a single lens may be used. The author's camera is 16 in. x 4 in. x 4 in., and the length of spectrum is two inches.

The direct vision prisms, P P P, can be replaced by a prism grating (see Fig. 25), the rest of the arrangement remaining unaltered.

CHAPTER II.

SOURCES OF LIGHT.

Before commencing to use the spectroscope for demonstrations in color, it is necessary to select a source of white light. There are two main sources of light, daylight and artificial light, both of which are derived from incandescence.

Of daylight there are three varieties:

(1) Sunlight (direct).
(2). Sunlight reflected from clouds.
(3). Skylight.

Sunlight is the natural standard of white light, and the same is said of sunlight reflected from white clouds (which are colorless masses of vapor). Skylight is bluer in color (see diagram below, Fig. 28).

Of artificial lights there are several:

(1). Electric arc light (direct).
(2). Electric arc light (alternating).
(3). Acetylene.
(4). Limelight.
(5). Incandescent gaslight.
(6). Incandescent electric light.
(7). Ordinary gaslight.
(8). Lamplight, etc.

Of artificial lights the electric arc light (direct current) is a very good substitute for sunlight. Care must be taken to avoid using the violet flame, and to employ the light from the incandescent crater only.*

The light from an alternating arc contains more violet and is more difficult of control. For projection by this light a large top carbon should be used, with an excentrical core to the front, a smaller bottom carbon placed in front of the top carbon and both carbons well sloped; by these means the rotation of the arc is avoided and one intensely bright spot of light secured.

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* In cases where it is important to use only the crater light, an image of the crater should be thrown on a screen in which is a hole through which the light from the crater only can pass. This condition is generally obtained when using electric light for spectroscopic work.

The acetylene light shows colors remarkably well, and should be a handy substitute for daylight.

The incandescent gaslight is colored compared with daylight, but on account of its power and uniformity it makes a convenient source of light to use.*

Electric incandescent and ordinary gaslight and lamplight are decidedly orange.

Comparison of Color.

Two sources of light can be readily compared for color by the Rumford shadow test (see Fig. 27).

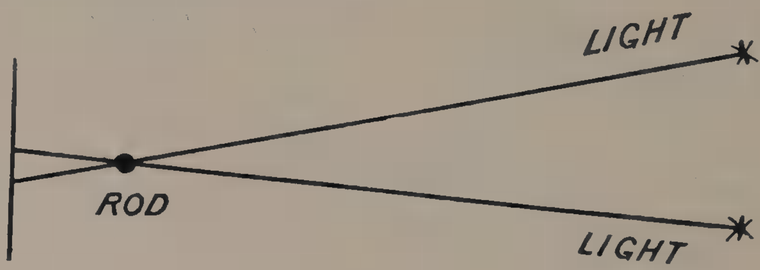

Fig. 27.

By altering the distance of one light, the two shadows can be brought to equal brightness, when the comparative colors can be exactly gauged. This is necessary in the case of very bright lights, which may appear whiter than they actually are.

For a complete test the spectrum of each light would need to be compared. Fig. 28 shows the relative proportions of the spec-

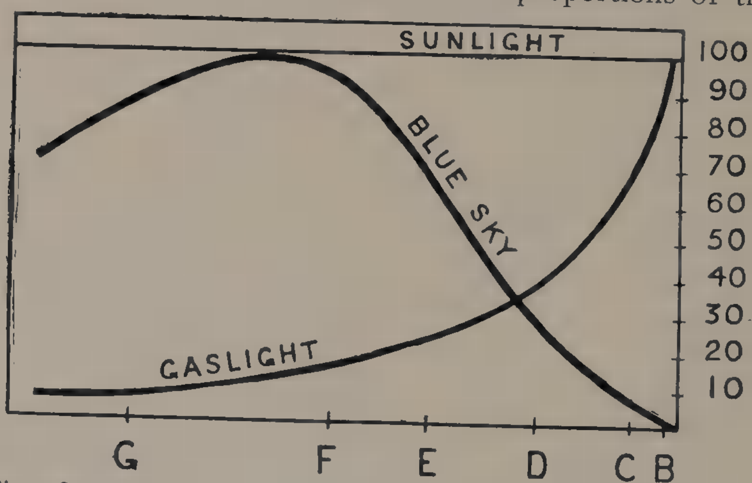

Fig. 28. Percentage composition of Various Lights (Abney).

* Two companies are supplying means for burning gas in mantles under forced pressure, by which means a greatly increased light is produced, which should be useful for photographic purposes where electricity is not available. Another company is supplying burners with mantles for burning petroleum vapor under pressure.

trum rays in gaslight and blue sky compared with the same rays found in sunlight. For convenience, every ray in sunlight is taken as 100 in value, the results are then read directly in percentages.

Influence of Colored Lights.

It is important to notice the influence that lights of various colors have upon pigments. An experiment will most readily show the differences produced. Take a colored chart or picture, place it in daylight, and observe it through pieces of colored glass; or the chart may be examined by light thrown on to it from a lantern through colored glasses. Or, again, the Rumford shadow test may be used. The two colored shadows are thrown on patches of pigment, when the brightness of the pigment in the two lights can be demonstrated. The experiment can be performed completely by ascertaining the spectral composition of the light under examination (Fig. 28), and the spectral composition of the pigment illuminated by white light (see Fig. 37). From these values a new curve can be made, from which the hue can be deduced.

In the construction of color sensitometers for orthochromatic and three-color work* it is important to consider the quality of the light in which the experimental work is made, and the light in which the work is to be done.

The same quality of illuminant must be used in adapting the color filters as was used in the examination of the test glasses for luminosity, or in matching them by three reproduction colors. Otherwise, if different lights were used in matching them, the relative brightnesses of the test glasses would be altered during the test.

When once the color filters are determined they may be used in any light, for the effect of variation of illumination will alter the relative brightness of the colors, and affect the eye of the observer and the photographic plate in proportion to the alteration.

It will be obvious that colors alter not only in brightness, but in hue also when illuminated by complex lights. Consequently, when a correct reproduction of the colored picture is made, the reproduction will be as the picture appeared to the eye in the particular colored light in which it was photographed.

To carry this idea further, a colored (or colorless) object might be illuminated by such color rays that when photographed on a perfectly orthochromatic plate it would give a negative suitable for a color record (see later, Position of Color Filters, page 150). The brightness of its hues would be altered, and the orthochromatic plate, which photographs according to the luminosities of the object, would give a correct rendering, in black and white, of the altered values.

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* See Selection of Color Sensitive Plates. Division III.

CHAPTER III.

DEMONSTRATIONS WITH THE SPECTRUM (I).

(A.) *Separation of Constituent Beams of White Light.*

The first truth to be demonstrated by the spectroscope is the splitting up of a beam of white light into its constituent colored beams. The spectroscope should be looked upon as a machine which takes in white light at one end and discharges it at the other in the form of separate beams. The light undergoes no other transformation (with the exception of a small amount lost by absorption and reflection).

(B.) *Separation of Constituent Beams of Colored Light.*

If a piece of colored glass be placed before the slit of the spectroscope the constituent colored beams are also spread out.

(C.) *Recombination of Constituent Beams of White or Colored Light.*

The separated beams may be recombined (by the method of Abney, see Abney's "Color Measurement and Mixture") by a large combining lens placed close to the focus of the colored rays. This brings all the emergent color rays to a focus, reproducing the light which entered the spectroscope.

(D.) *Abstraction of some Constituents from White Light.*

If across the spectrum of white light an obstruction be placed, some of the rays are prevented reaching the combining lens, and the recombined patch will be colored instead of white. To secure this a rod like a pencil, or a small right-angled prism, or a narrow-angle prism, or a narrow strip of mirror, may be used. To secure partial absorption of the color, the obstruction can be placed partially across the spectrum. (See Mr. Shelford Bidwell's book, "Curiosities of Light and Sight," Chapter ii.; also Abney's templates for the spectrum in "Color Measurement and Mixture," Chapter viii.)

Deductions from Experiments.

The above demonstrations are of great importance in a study of three-color work. From them we learn:

(1). That white light has a composite nature.

(2). That the constituent colors of white light are invisible to the unaided eye.

(3). That a colored beam also may consist of other colored beams, or is composite.

(4). That the eye is unable to analyze the constituents of a colored beam.

(5). That a colored beam, though composite, shows no evidence of more than one color; that is, it is one-hued.

(6). That by abstracting some of the constituents of white light colored beams are produced.

(7). That color vision may be regarded as an optical illusion.

Dominant Hues.

It is convenient to call the color of a combined beam a "resultant" or a "dominant" hue. Thus the resultant color due to a rod across the green of the spectrum is pink.

Complementary Colors.

The complementary of a color is that color which must be added to it to produce white. Taking the example above, the green and pink are complementary to each other, thus—green + pink = white.

Minus Colors.

By abstracting green from the spectrum of white light, pink is produced. Thus, white minus green is pink. We may give a name to the hue formed by the subtraction of green from white by calling it "minus green."

In the following list of complementary colors each is "minus" (—) to the other.

Red	+	Greenish-Blue	=	White.
Yellow	+	Blue-Violet	=	White.
Green	+	Pink	=	White.
Greenish-Blue	+	Red	=	White.
Blue-Violet	+	Yellow	=	White.
Pink	+	Green	=	White.

By transposing one hue to the other side of the equation we get

Red = White — Greenish-Blue

(or, what is equivalent to the transposition, by subtracting the same color from each side, thus,

Red + Greenish-Blue = White,

(See table of complementaries above.)

Now subtract Greenish-Blue from each side,

Red + Greenish-Blue — Greenish-Blue = White — Greenish-Blue,

resulting in Red = White — Greenish-Blue)

The physical interpretation of this is that Red is produced by the abstraction of Greenish-Blue from white light.

The importance of these "minus" colors is seen in all experiments in three-color theory.

Thus a yellow pigment is printed on white paper, its function is to absorb violet, and it may therefore be called a minus (—) violet pigment (*i.e., a violet-absorption pigment,* see Chap. XIV.), and the white paper reflects all the rays of white light minus the violet constituent.

CHAPTER IV.

SOURCES OF COLOR. COLOR IN NATURE.

It will be useful to consider how color is produced in the objects which are placed before the camera to be photographed in colors.

White light is the principal source of all color, and by the action of bodies on white light colored beams are produced.

The phenomena which arise are: Transmission, Absorption, Refraction and Dispersion, Diffraction, Interference, Polarization, Opalescence, Fluorescence, Phosphorescence, and Calorescence, and some others of minor importance.

It may be necessary to photograph colors produced in any of the above ten ways, and it can be shown that the color effect in each is identical.

We will take these phenomena in order.

Absorption and transmission are complementary, and so may be considered together.

If a beam of white light falls upon a substance which selectively absorbs some of its constituents, allowing the remainder to pass on, the emergent beam will be colored. This is called selective absorption. A study of this is of so much importance that the next chapter will be devoted to it.

As we have previously seen in the spectroscope, the unequal refraction of the constituent colored beams of white light produces dispersion, or a fan-like separation or spreading out of the colored beams.

By diffraction color is produced by the mutual interference of the waves of light. This method can be used instead of prismatic dispersion to produce the spreading out of the constituent rays of light. A diffraction grating or a fine ruled screen (such as is used to make screen negatives) shows this.

Interference colors, as seen in opal and mother of pearl, also in soap bubble.

Polarization. In this particular instance only is the light changed in character.

Opalescence, or scattering by turbid media. Haze is produced by this means, also the blue of the sky; cigar smoke and opal glass show it. A solution of hypo. into which is dropped a weak solution of acid, by the separation of minute particles of sulphur, shows this phenomenon very well. The constituents of white light falling

on the scattering material suffer different amounts of scattering, the red or longer waves are transmitted and the blue reflected.

Fluorescence is an alteration of wave length from shorter to longer. A solution of sulphate of quinine, paraffin oil or fish-glue, spread on black paper, and placed in the ultra-violet spectrum, renders it visible by the production of a bluish color.

The color beams are the same in each case, and so it will not be necessary in photographing color to consider what the source of the color is. Reference should be made to some text-book on color, such as Professor Church's, for an account of the occurrence of color in nature. Here we are only concerned with the fact that, however produced, the colors in nature are of the same character exactly. The corollary to this is that colors from any source whatever can be photographed. The sole distinction is that colors in nature are collections of the pure spectrum rays. Hence it will not matter whether it is the color of a flower, the blue of the sky, the iridescence of mother of pearl, or Barton's buttons, the spectra from diamonds or candelabra, a section in the polariscope, a self-luminous matchbox or a glow-worm.

It cannot be too distinctly emphasized that there is no difference between colors as seen in nature and those produced by the spectroscope. It is for this reason that we are correct in employing the spectroscope as a source of pure color in experimental work.

CHAPTER V.

THE PRODUCTION OF COLOR BY SELECTIVE ABSORPTION.

The principal source of color in nature is white light from which some of its constituents have been removed. The colored substance may be transparent, in which case the color is seen by the transmitted rays, or opaque, in which case the rays not absorbed are scattered from the surface in the direction of the eye.

By placing across the spectrum of white light an opaque obstruction some of the rays are stopped; the remainder when combined form a color patch. In a precisely similar manner color is produced by bodies. Colored bodies possess the power to quench partially or totally some of the rays of white light incident upon them, reflecting or transmitting the remainder to form a hue which we call the color of the body.

It is convenient to regard colored bodies not as being colored in themselves, but as having the power of stopping certain rays. Thus, a red glass or a red pigment should be regarded as stopping the blue and green of the incident white light and transmitting or reflecting red only. This considerably simplifies color pigment problems. (Page 129; also page 98.)

To demonstrate this the spectrum of white light should be thrown on a white screen, then interpose a piece of colored glass either at the slit or anywhere in the path of the rays, as, say, at the eye, when some of the rays will be seen to be diminished in brightness. If placed half way across the slit the unaffected and the reduced rays can be readily seen, and, by suitable photometric methods (Chap. viii., Abney's "Color Measurement and Mixture"), can be compared; also, the rays constituting white light may be caused to fall upon an even patch of pigment, when some will be seen to be reduced in brightness or entirely quenched.

It is immaterial, therefore, whether the coloring matter is in the form of colored glass or of a pigment spread on paper, and it is convenient in color pigment problems to consider the pigment as in a transparent form, as in glass.

If necessary, a chart could be constructed to show the diminution in each spectrum ray caused by the colored pigment.

For this purpose it is convenient to consider that all rays of the spectrum are of value 100 and then the absorption can be shown in percentages. Fig. 29 shows the absorption of spectrum rays by

typical red, green, and blue glasses. Fig. 37 shows the absorption of spectrum rays by emerald green paint.

Two Pieces of the same Red Glass.

It will be convenient here to consider the effect on the spectrum rays of two pieces of the same colored glass. Let us take, for instance, the red. At scale No. 7¾ the red glass transmits 2 per cent. of the green rays, two thicknesses will therefore transmit 2 per

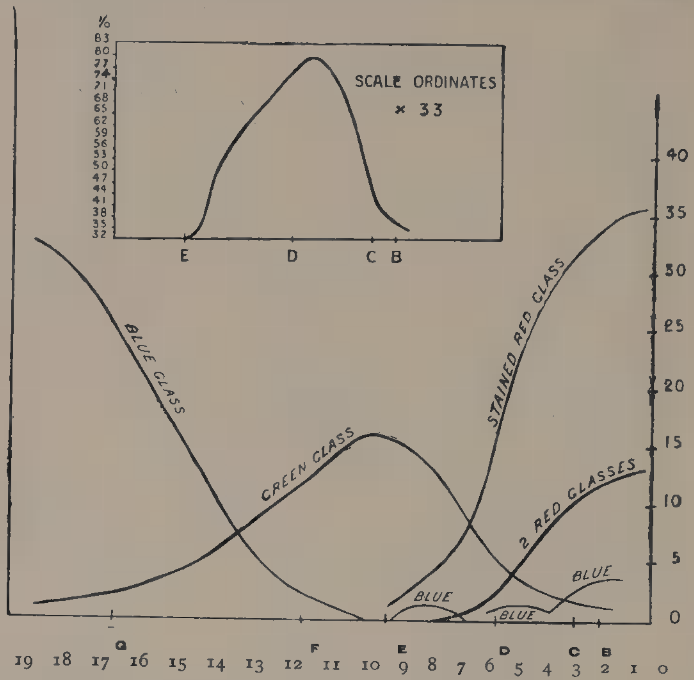

Fig. 29. Absorptions of typical red, green, and blue glasses (Abney). Also effect of two thicknesses of red. Also the mutual transmissions of a red and green glass. (See small figure, which has its scale of ordinates multiplied by 33.)

cent. of this, which gives .04 °/₀. At scale No. 7 2½ per cent. is transmitted, therefore two thicknesses transmit 2½ x 2½, or .06 per cent., and so on in geometrical proportion.

Scale number.	One thickness transmits %	Two thicknesses transmit %
7¾	2	.04
7	2½	.06
6	5	.25
5	10	1.00
4	20	4.00
3	28	7.84
2	33	10.89
1	35	12.25

These values are indicated in the curve, which shows that not only is the total light much reduced, but that the relative amount of pure red is much increased.

Such an experiment can readily be performed, and if a spectroscope be employed also the reduction of some of the constituent colors can be easily seen.

By increasing the number of pieces of glass or thickness of colored solution, etc., the effect can be still further increased. If a ray is freely (100 %) transmitted by one piece of glass it will suffer no absorption by passing through any number of such pieces.

Mutual Transmission of Red and Green Glasses.

From the data in the same figure the mutual absorption of the two glasses, red and green, can be calculated and the composition of the emergent rays seen. It is only where both curves exist that any light can get through. The whole of the violet, blue, and green, as far as scale number 8, is absorbed.

At Scale Number	Red transmits	Green transmits	New curve
8	2%	16%	.32
7	2½	15	.375
6	5	12	.60
5	10	7	.70
4	20	4	.80
3	28	2½	.70
2	33	1¼	.41
1	35	1	.35

The new curve, which is shown on an enlarged scale of 33 times, has its maximum at about scale No. 4, which is at the D line, and so would be a yellow-green, but of a very degraded tint (low luminosity).

In a similar way the color of any number of pieces of glass can be estimated.

Colors of Natural Objects.

Besides pigments, natural bodies owe their color to the same cause, which can be readily shown by illuminating any colored objects by the separate rays of the spectrum, which rays they will return more or less fully. It should be distinctly understood that natural objects owe their color to the abstraction of only a small amount of color from the incident white light. Thus, were photographic plates entirely insensitive to red and yellow, a red flower would not impress the plate; but a red flower reflects many rays of the spectrum besides those associated with its name-color, and by these it would

be photographed, though not to the extent that it would were the plate sensitive to red and yellow.

It should be noted that the color of a body is dependent on the color of the light by which it is seen (page 95).

Instructive experiments can be made by superposing pieces of colored glass or dyed gelatine films, and examining white light through them.* The colors to which they are mutually transparent are transmitted. Not only the classical example of blue and yellow making green, but every color of the spectrum can be produced in this way. A little attention and experiment at this point will be of great use to the student.

The pigments used for printing in three-color work are chosen to give, by their mixture, all the colors and in their brightest shades.

The following combinations should be tried:

Yellow and blue**	giving green.
Yellow and pink**	giving red.
Pink on blue**	giving violet.

What has been mentioned about the mutual transmission of color rays by glasses is equally true of pigments, a fact of great importance.

The importance of the subject of selective absorption is great. It accounts for the color of the object photographed, the effectiveness of color filters is dependent upon it, and the colors of the final result printed in pigments are due to it.

For a fuller account of the occurrence of color produced by selective absorption and other phenomena, reference should be made to Rood's "Modern Chromatics" or Church's "Color."

* The pigmentary substances may be in the form of colored glasses, colored films, solutions of dyes or metallic salts, colored powders—dry, or in a vehicle as paints.

** The order of superposition is, in general, immaterial. Page 127.

CHAPTER VI.

DEMONSTRATIONS WITH THE SPECTRUM (2). SINGLE AND TRIPLE SLITS.

By the employment, at the focus of the colored rays, of a plate in which is a slit and which can be moved across the spectrum, a narrow slice of color can be obtained, and by using the large combining lens an image, in this color, of the first surface of the prism can be obtained. By sliding the slit across the spectrum all the colors can be obtained in turn, forming on the screen patches of light of the same size and in the same position.

This, when performed in a dark room, affords an excellent way of observing the hues of the spectrum at different points without distraction from surroundings. It will be noticed that the various hues differ in brightness. This can be readily compared with a beam of white light reflected from the first surface of the prism (see diagram of color patch instrument in Abney's "Color Measurement and Mixture"). Each color, therefore, in a spectrum produced under certain conditions, has its relative brightness or luminosity. When speaking of a color it is convenient to refer to it as a hue. Hue is the name given to what is commonly known as color without reference to other attributes. When the hues are produced so that there is freedom from white light they are spoken of as saturated or pure.

Color Constants.

These three attributes of color or color constants, hue, luminosity and purity, are sufficient to correctly describe the color, for the hue may be referred to the wave length,* the luminosity may be referred to a standard of light, and the purity may be stated as the relative quantity of white light required to be added.

This may be demonstrated by forming a monochromatic patch on the screen, and allowing a beam of white light to fall on it, when the color is lightened and made less saturated or impure.

It would be convenient to use the word color when all three con-

* As will be seen later (Physiological Perception of Color), though, to the normal eye, change of wave length denotes change of color, the converse of this is not true, for the yellow of the spectrum, for instance, can be ocularly demonstrated to be simulated by red and green light.

stants—hue, luminosity, and purity—are implied, as a color is correctly denoted by these terms. Often, however, when hue is meant the word color is used.

The Possibility of Measurement.

One experiment is of great importance, as on it depends the fact that measurements of colors can be made. If a slit be used to produce a patch and the brightness of the patch be estimated photometrically, and a slit of another color be used to throw a second patch on the first and the brightness of this be measured, the brightness of the combined patches is equal to the sum of the brightness of the separate patches. More than two patches can be used, and, as will be seen later, it is generally with three patches that we have to deal. In general, the brightness of white light is equal to the sum of the brightness of its component rays. This is so, both visually and photographically. This fact is the basis of all quantitative measurements in color. Its immediate consequence is the relative luminosity and photographic opacity due to white and color. Thus, if the opacity due to a beam of red light is 40, and to a beam of green light is 55, and to a beam of violet light is 5, then the opacity due to the combined beams is 100.

It should be noticed that the amount of color and brightness are (within limits) convertible terms.

Brightness is the *visual* effect of a definite amount of color.

Hence the amount of color is measured in terms of brightness.

DIVISION II.

THE PRINCIPLE.

THE THREE-COLOR THEORY OF VISION AND ITS PHOTOGRAPHIC PARALLEL.

The Perception of Color a Physiological Phenomenon.

CHAPTER VII.

CONDITIONS NECESSARY FOR CORRECT COLOR VISION.

So far color has been discussed without reference to the eye of the person seeing the color, or rather it has been supposed that the eye has normal color vision. The three-color constants, it has been stated, define exactly the color, but this statement has to be qualified; that is, it is only correct under certain definite conditions. It has also been said that wave-length defines the hue, but the converse of this is not true. Hue is not always associated with the same wave-length, as will be shown in experiments with the triple slit (Chap. VIII.). The perception of hue is affected by certain physiological conditions.

Color Blindness.

A small percentage of persons are partially color blind; that is, incapable of seeing to the fullest extent some hues which affect the red, green, or blue color-seeing nerves. This is apart from the inability of the eye to distinguish between hues, which defect can be overcome by experience.

Size of Image.

Parts of the retina of the eye are not equally sensitive to the same colors, consequently the color perception will vary according to the disposition of the image on the retina. Besides the blind spot which most people know exists, there is, directly on the axis of the eye, and in the place of most distinct vision, a yellow spot called the "macula lutea." When the image of a small or distant object falls on the retina, which it does when the axis of the eye is turned towards the object, it is entirely received by the yellow spot, but if the object be large or close its image is not entirely confined to the yellow spot, and consequently is not so absorbed by it. A patch of bluish-green color will, therefore, appear to differ in hue according to its apparent size. One's impressions of hue are gained by incessantly shifting the axis of the eye to receive the images on the most sensitive spot, and hence normal vision may be said to be that which is confined to the yellow spot.

Consequently, in experimental work on color, it is advisable to limit the size of the patches so that the images may fall entirely on the yellow spot. Patches of color one inch square viewed at six feet distance, or smaller or larger patches at proportional distances, will fall entirely on the yellow spot.

Brightness of Illumination.

The brightness of illumination of colors also affects the perception of hue by the eye. It is found that when the brightness of a spectrum ray or pigment is very much reduced its hue alters.

There is a certain minimum of illumination below which color patches should not be viewed. This is fixed by Abney as the illumination of a pigment by a candle at four feet distance.

Besides the above there are other circumstances, such as contrast, etc., which influence the judgment.

CHAPTER VIII.

ALL HUES COUNTERFEITED BY THREE. USE OF THE TRIPLE SLIT. DEMONSTRATIONS WITH THE SPECTROSCOPE (3).

Experience has shown that in order to reproduce all the hues of the spectrum three hues only need be employed. By placing a slit in the red of the spectrum, another in the blue-violet, and another in the green, and combining the colored beams into one patch, various hues may be produced by varying the amounts of the hues coming through their respective slits.

Positions of Slits.

The positions to be chosen for the red and blue slits are near the ends of the spectrum, and near the red and blue lithium lines respectively at about wave-lengths 6,705 and 4,600 (see Abney's "Color Measurement and Mixture," Chap. IX.). The position of the green slit is at E, wave-length 5,140, though for particular reasons some latitude of position is convenient (see page 119).

Relative amounts of each hue.

With the slits in these positions we require next to find the relative amount of each hue. This is readily done by allowing all three beams to fall upon a white screen and altering the widths of the slits until a white is produced, which may be compared with the unaltered white beam reflected from the first surface of the prism. It is convenient to have a standard amount of each hue (the importance of this is referred to later, see pages 166 and 179. This standard is, for convenience, the relative amount of each hue required to make white, though other conventions might be adopted (page 167).

This white beam, produced by three pure hues only, is in every way identical to the eye, with the reflected white beam. Though chromatically equivalent to the other beam, optically it is different, as may be tested by observing the white patch on the screen by a spectroscope, which resolves it into the three narrow bands of the spectrum chosen to form it. By opening one or two of the slits other colors can be formed. Thus the red, green, and blue opened separately give three main divisions of color. By fully opening the slits in pairs the red and green give yellow, the red and blue give pink, and

the green and blue give greenish-blue, completing the six main divisions of color. By altering the relative widths of the slits in pairs, hues intermediate to these can be produced; thus more red and less green give orange, more green and less red give yellow-green, more green and less blue-violet give bluish-green, and less green and more blue-violet give a purer blue. Using only the blue and red slits, pink hues inclining to blue or red can be produced according to the relative widths of slits (see diagram, Fig. 31).

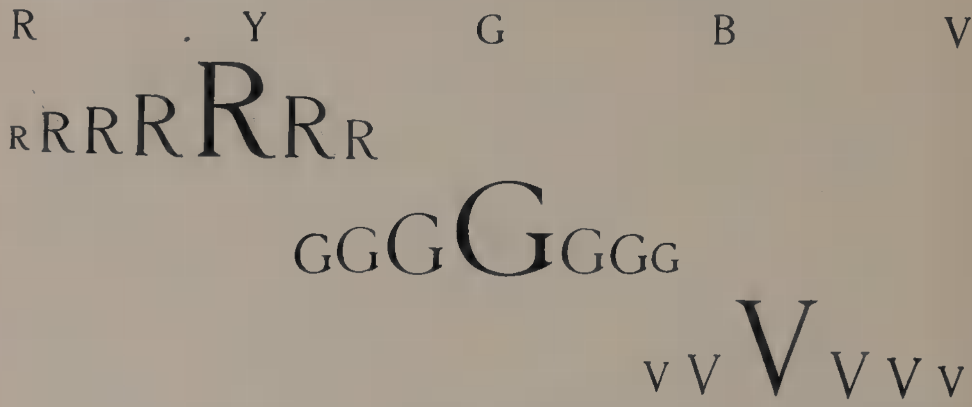

Fig. 31. Diagrammatic representation of the amount of each reproduction color required to imitate the spectrum colors.

By using suitable amounts of the three reproduction hues *any* desired color can be produced.

These results are shown in tabular form below, where the widths of slits are not stated, but the amount (brightness) of each color transmitted is given (see page 106).

38 R	plus 60 G	yields	98 Y
60 G	" 2 V	"	62 B
38 R	" 2 V	"	40 P
38 R	" 60 G plus 2 V	"	100 White.

All slits closed yields black.

As already pointed out this result is quantitative as well as qualitative. If the brightness of the lights coming through the red, green, and violet slits be 38, 60, and 2 respectively, the brightness of the white light will equal 100 (38 plus 60 plus 2). The brightness of the yellow, pink, and blue hues resulting from these mixtures is given in the table (these are approximate values).

Graphical Representation of Results.

The intermediate colors can be imitated in hue and brightness, and the quantity of each of the three standard colors required can be measured and the results recorded in a table, or a curve,* or

* See Chap. IX., Color Mixture Curves.

diagrammatically, as Fig. 31, where the top line indicates the color to be matched, and the size of the letters the widths of slits or amounts of issuing rays.*

Simple Experiments of Fundamental Importance.

Every student should endeavor to see or to perform these experiments, which are of fundamental importance. They form the basis of the three-color method of color photography, and a perfect understanding of them is absolutely essential. The apparatus described on page 126, which is within the reach of any one, is capable of showing the above results perfectly.

Primary, Reproduction, or Standard Colors.

It should be particularly noted that these three colors, which may be called primary,** standard, or reproduction colors, are capable of counterfeiting every color and every shade of color whatever, and so are suitable as a basis for color photography. The derived colors are chromatically equivalent to the spectrum hues which they counterfeit. No ocular evidence of the reproduction hues employed exists in the derived colors.

Lightened hues.

Besides the pure colors already instanced, variations of these, called *lightened* colors, can be produced by adding to the pure hue a certain amount of white, which can be effected by opening to the necessary extent all three slits. Thus a light blue can be made either by opening the slits in the green and violet and throwing some white upon the patch, or by opening the green and violet slits still more and also the red slit. When the relative openings of the three slits are sufficient to make white, any further opening of the green and violet slits will make a bluish-white.

Degraded hues.

Degraded hues (which are commonly called tertiary colors) are hues of low luminosity. The effect is one of comparison. Thus, the

* The amount of each hue can be varied by Abney rotating sectors or by altering the width of the slits; this latter method is very convenient in some experiments. The widths of slits can be measured by forming enlarged images by means of a lens and screen at fixed distances from the slits. The slits to be measured are moved into the same position, that is, are measured in the same monochromatic light.

** Every hue of the spectrum may be called primary on account of its being no further capable of analysis by spectroscopic means. Strictly speaking the real primaries are deep spectrum red and the two unrealizable fundamental colors (see page 119). To prevent confusion it is preferable to call the colors used in practice, whether derived from the spectrum or by selective absorption, *reproduction colors.*

color of brown paper can be readily matched by opening the three slits sufficiently to give an orange tint, and if this be very much reduced in brightness (as by rotating sectors) a *degraded* hue will be produced equalling the brown paper in color, that is in hue, luminosity, and purity.

Suggested simplicity of the visual apparatus.

The inability of the eye to analyze colors which are compound, such as a yellow composed of red and green, and to differentiate between a yellow ray formed in this way and one taken from the spectrum, suggests that the eye does not possess a color-seeing apparatus for each simple color of the spectrum. For were it so it is reasonable to suppose that the eye would perceive the constituents of such compound colors. The above experiment suggests the possibility that there need be no more intricate color-seeing mechanisms in the retina than those that are capable of seeing red, green, and blue-violet respectively.

Red, green, and violet are separately visible, and we may suppose that there exists in the eye means for perceiving these colors; yellow (*compound*) is perceived by its red and green light reaching the eye and affecting the red and green seeing apparatuses simultaneously, and we may suppose that the *spectrum* yellow produces its effect in the same way by influencing the same apparatuses.

Similarly other colors,which can be imitated by mixing the red, green, and blue-violet rays, affect the red, green, and blue-violet seeing apparatuses. Thus, pink or purple is produced by acting on the red and violet seeing nerves by red and violet, and blue by simultaneous action on the green and violet seeing nerves. White is due to the stimulation of the three apparatuses in due proportion.

Color nomenclature.

Any color may be referred to its action on the three nerves, and so it is obviously possible to define the hue of any color by two terms only. Suppose a color causes stimulation of all three nerves, a certain proportion of this stimulation will cause the perception of white, the rest affects two nerves; the hue of the color, therefore, lies between two standard colors, and the color is completely expressed by stating its hue in two-color terms contiguous in the spectrum plus so much white. Thus, suppose a color is matched by 3 parts of blue, 200 of green, and 100 of red, and that 2 parts of blue, 60 of green, and 38 of red give 100 parts of white, then, also, 150 parts of white are formed by 3 parts of blue, 90 of green, and 57 of red. Subtracting this from the color, thus:

	3 blue	200 green	100 red	= color
Subtract	3 blue	90 green	57 red	= white
Leaving		110 green	43 red	

excess of stimulation above that required to form white. Now, if it be taken that 38 parts of red and 60 parts of green or 1 part red and 1.6 part green form a yellow which inclines neither to orange nor greenish-yellow, then 43 parts of red require 69 parts of green; hence, subtracting these quantities,

	110 parts green plus 43 red
Subtract	69 parts green plus 43 red = yellow
Leaving	41 parts green

The balance of stimulation is caused by the green, and the color is a *lightened green-yellow.* Every color can be similarly defined by two color terms.

For the indefinite number of hues, we require to use only the six terms, red, yellow, green, blue, violet, and purple. Colors intermediate between these are named by using two of the terms, as yellow-green, or greenish-yellow, where the second term denotes the preponderating color.

Use is made of the common names of the colors, but it must be understood that this is for convenience only. The colors are defined by their wave-lengths; when red, green, and blue-violet are spoken of, the colors emerging through the slits in the positions indicated by the wave-lengths λ 6705, λ 5140, and λ 4600, are meant; similarly for yellow, blue, and pink or purple; of these, yellow and blue can be referred directly to the spectrum, and pink indirectly as the complementary of green.

Pink and purple, also blue, blue-violet, and violet, are carelessly mentioned indiscriminately.

CHAPTER IX.

MAXWELL'S COLOR MIXTURE CURVES. VARIATIONS OF THESE CURVES.

We must further consider the subject of color vision. Dr. Thomas Young suggested a theory of color vision which depended on the existence of three fundamental color sensations.

Von Helmholtz adopted it and gave diagrams. Professor James Clerk-Maxwell* experimented with a modified spectroscope called a "color-box," and mixed the simple colors of the spectrum in different proportions to match a given white. From the equations thus obtained he found what amounts of each of the colors which he took as his standards were required to make white and to match the other colors of the spectrum. These he tabulated, and drew curves to show graphically the amount of each of his standard colors required. The base of the curve was the scale of his spectroscope, and the heights

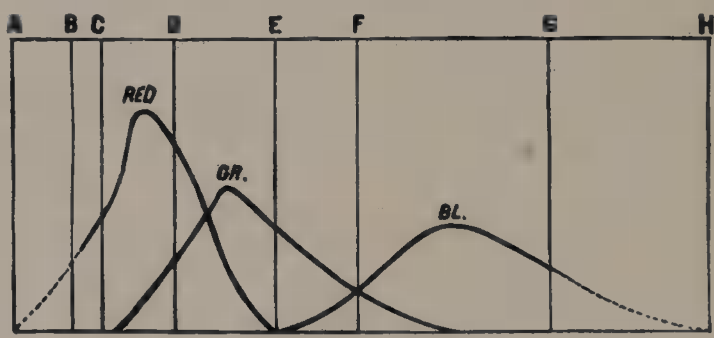

Fig. 32. Maxwell's Curves.

of the curves at any point denoted the amounts of the standard colors. (Fig. 32.)

Now, to be of general utility, the base-lines or abscissæ of these curves should be drawn on the scale of wave-lengths; the value of the heights of curves (ordinates) should have some common unit, and the standard colors should be correctly chosen. Maxwell's curves are drawn to the scale of his own spectroscope, and need converting into a wave-length scale to be comparable with results obtained by other spectroscopes, and this will have the effect of altering the ordinates. On the wave-length scale the red end of the

* Published in the Philosophical Transactions of the Royal Society, 1860.

spectrum is more spread out, and the curve will be lowered. At the blue end the cramping or condensation of the colors is greater, and the curve will rise. This is shown in the two figures, where the

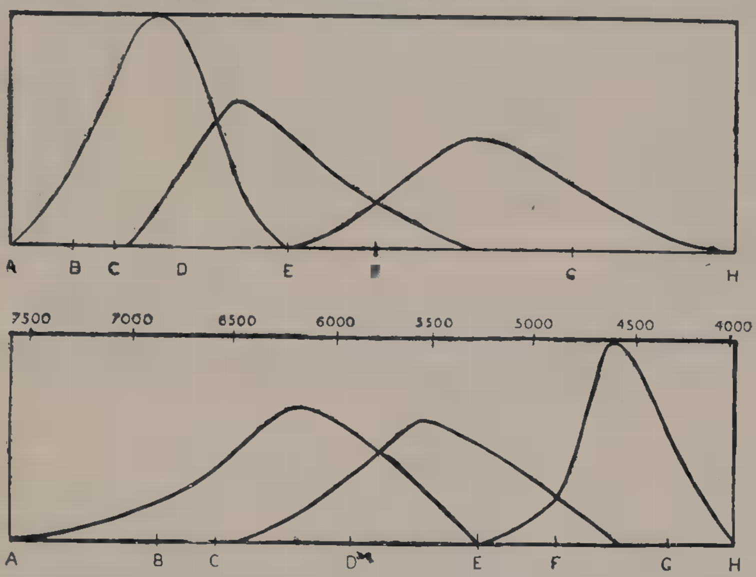

Fig. 33. Maxwell's Curves to scale of his Spectroscope (top) compared with the same Curves on scale of wave-lengths (below).

effect at the two ends is almost reversed. Compare the base-lines and heights of figures. (Fig. 33.)

The effect of this is to alter the amount of color distribution in the spectrum, and to alter the luminosity curve.

Again, it is necessary, in order that the curves may be comparable one with another, that they should be referred to some common unit of ordinate. Two kinds of unit are employed: one kind directly involves the amount (*i.e.*, luminosity, see page 106) of color used, and the other indirectly so. The units in this latter case are the *relative* amounts of the reproduction colors, which, when combined, give white.

Scales of Ordinates.

In the luminosity curves the luminosity of each color of the spectrum is taken as of 100 parts in value (luminosity units). The luminosities of the three standard reproduction hues which are required to match the color are then shown in percentages. (Fig. 34.)

Example.—Taking the luminosities of all colors of the spectrum as equal to 100, at scale No. 52 the luminosity is composed of 71.4 per cent. of red and 28.6 per cent of green. (71.4 red + 28.6 green = 100 orange.)

In another form of luminosity curves each color of the spectrum is taken at its actual luminosity value, and this is subdivided into the luminosities of the reproduction hues employed to imitate it.

Example.—The luminosity of the spectrum (prismatic electric light) at scale reading 52 (red side of D) is 96 units, and this orange hue is imitated by 69.1 luminosity units of red and 26.9 luminosity units of green (69.1 red + 26.9 green = 96 luminosity units orange).

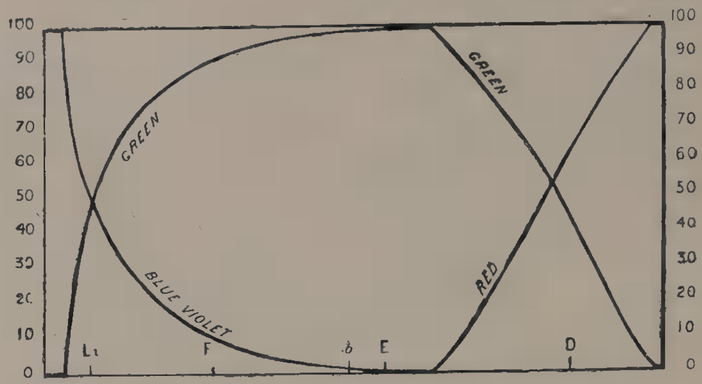

Fig. 34. Percentage composition of Spectrum Colors in terms of Colors transmitted by three glasses (Ives' viewing screens). (Abney.)

Again, the scale of ordinate may be one of *parts* of each color, where each *part* is the relative quantity used in making white light. Equal heights of ordinates of red, green, and blue will then give white. Mixing the red, green, and blue lights in various proportions the other spectrum colors are produced, and the quantities employed are shown in curves whose base-line or abscissa is on an arbitrary scale or a scale of wave-lengths and the height of the curves is in a scale of *parts*. (Fig. 36.)

The value of each *part* in terms of luminosity units can be given. Thus, taking one *part* of red as equalling one luminosity unit, a *part* of green and a *part* of blue are respectively equal to 2.12 and 165 luminosity units.

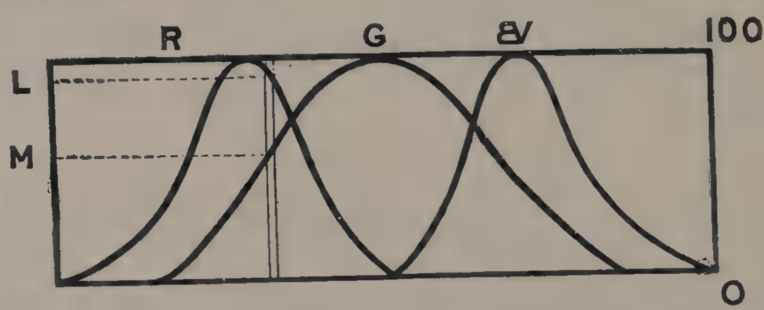

Fig. 35. Utilization of Maxwell's Color Mixture Curves.

The student must be on his guard, therefore, to notice exactly what scale he is dealing with, both for ordinate and abscissa. It should be noticed that the shape of the curve will also differ according to the absolute scale of the ordinate. Thus, luminosities may be represented by lengths which may be inches or feet, at will.

Quantitative application to all spectrum colors.

Resuming from pages 109, 110, and 111, we see now that to ascertain the amounts of the reproduction colors required to imitate any spectrum color, color mixture curves, such as Maxwell's, in which equal ordinates give white, modified, if necessary, to suit the reproduction colors, must be employed.

Draw two lines close together to represent a narrow slice of the spectrum, and by inspection the amounts of reproduction colors can be seen. Thus, the orange requires an amount of red light indicated by L, plus an amount of green light indicated by M, to reproduce it.

CHAPTER X.

COLOR MIXTURE CURVES AND COLOR SENSATION CURVES.

What appears to be a properly chosen primary* spectrum color does not necessarily stimulate only one color sensation nerve, and if the primary colors themselves stimulate more than one sensation, we do not get a correct estimate of the amount of stimulation of each sensation due to the remaining colors of the spectrum. Maxwell chose as his standards colors which are not the fundamental sensation colors. Later investigations (Abney) prove this, as does also the fact that his tabulated results show negative values. Thus he matched the color at scale number (52) by — 3.4 red, + 31.4 green, + 17.5 blue, or, otherwise, by transposing the red, the color at (52) + 3.4 red was matched by 31.4 green + 17.5 blue. Thus by adding the red to the color at (52) a small amount of white was produced, and this *lightened* color was capable of being matched. It will be at once recognized that the curves to be serviceable in practice *should have positive signs.* It would not be possible, for instance, when imitating a natural color, to add a little color to it, though in spectrum experiments it is both possible and convenient to do so.

When spectrum colors are matched by three slits in the red, green, and blue, the matches, though perfect in hue, are too pale. A good example of this is in the orange of the spectrum. The orange spectrum color can be imitated by two slits only, red and green, but this match, though perfect for hue, is too pale, because the green light also affects the blue sensation. Thus, all three sensations are affected by the match, and the color is *paled* orange. Similarly with the other spectrum colors various amounts of impurity are introduced in the matches. This will be seen by reference to a figure showing the curves of color sensations in which equal ordinates give white, as in Fig. 36. The consequence of this is that some *spectrum* hues cannot be *accurately* imitated both in hue and purity by two reproduction colors. The made color is always less saturated, and this, from the nature of things, is unavoidable.

It will be noticed that Maxwell's curves differ considerably from the true sensation curves, and it is necessary to point out the difference so far as it affects color photography. The colors that are available for producing color mixtures are the spectrum hues red, green, and blue. Now, the sensation curves show that the red

* See footnote page 111.

below C affects only one sensation nerve, the green always affects three, and the blue always affects two; that is, the purest red that can be taken from the spectrum affects one sensation, the purest green three, and the purest blue two, and these are the *simplest* colors we can employ. We are unable to obtain a green or a blue which will

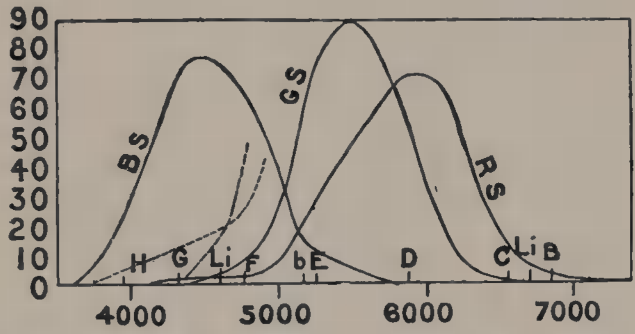

Fig. 36. Sir W. Abney's Sensation Curves, (Prismatic spectrum) in which equal heights of ordinates form white.

affect one sensation only, and therefore we have no need in practice for the sensation curves, but only for curves which will tell us what proportions of the simple colors we have chosen are necessary to reproduce the other colors.

These we have in Maxwell's curves, which we call *color mixture* curves, and which represent the amount of each standard spectrum color required, due regard being given to the scale, and to the fact that his reproduction colors are not quite correctly chosen. (The red is too orange, and the green too yellow.)

Abney gives in his latest determinations the position of the slit for red as near C, λ 6705, and for the violet slit near the blue lithium line at λ4600, and the position of the green slit at λ5140. To suit one's purpose the position of the green slit may be shifted slightly, and for this reason the three sensation curves (*consider curves where equal heights of ordinates give white*) of red, green, and blue have considerable height near where the green is purest, and a position of slit is chosen where the red and blue curves intersect and with a similar amount of green give white (*i.e.,* equal heights of all three curves); the surplus green then is the purest green possible, for it is only mixed with white. As the green curve is not very high at this place, the proportion of green remaining over, after forming white, is small, and the green, though pure, is therefore *pale.* This position of purest green, where it is neither blue nor yellow, but only mixed with white light, is near "little b."

If a position for the green slit be taken where the green curve is highest, say midway between "b" and D, or a yellow green, a large amount of red is also stimulated, which would not give a correct reproduction color, though it would not be so pale. It is necessary, therefore, to compromise, and select a green at about E, where there

is neither too much white light nor too much red. This was done by Mr. Ives in the reproduction colors used in the Kromskop.

General utility of the Sensation Curves.

Abney's curves constitute a set of standard curves to which all others may be referred, and in terms of which they may be expressed.

Thus, knowing the values of a set of reproduction colors in terms of the fundamental sensation colors, these values may be introduced into the sensation curves without further experiment, giving rise to a set of curves in which the new reproduction colors are employed.

Again, knowing the values of a set of Kromskop projection glasses in terms of the fundamental sensation colors, or in terms of Maxwell's reproduction colors, these values may be introduced respectively into the sensation curves, or Maxwell's curves.

From these curves the amount of white light introduced by the employment of (incorrect) reproduction when imitating spectrum colors can be calculated.

CHAPTER XI.

EXPLANATION OF SPECTRUM EXPERIMENTS ON THE THREE-COLOR THEORY. DOMINANT HUES.

We shall now be able to explain the results of our experiments on pages 96 and 97.

(2d.) The constituent colors of white light are invisible to the unaided eye because all the simple colors of which it is composed stimulate the three color-seeing nerves in the correct proportion to give white; thus there is a balance of effect and no (dominant) color is produced.

(3d, 4th, 5th, and 6th.) If not in proportion to give white light, as when the rod was placed across some color, the resultant hue is due to the excess of stimulation of one or two of the nerves.

The diagram will help to make this clear.

The red and the colors from red to green affect the red-seeing nerve, the colors from orange to blue affect the green-seeing nerve,

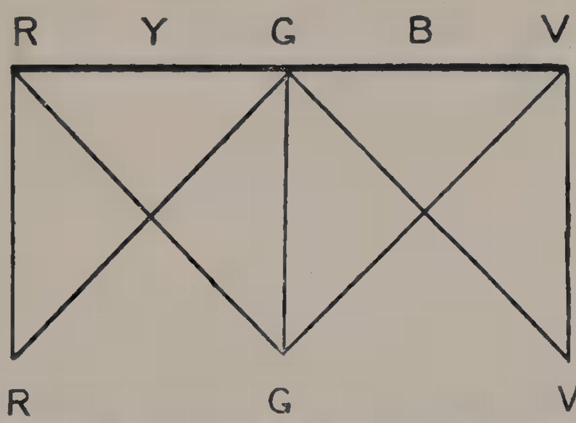

Fig. 37. To illustrate the effect on the three sensation nerves, R, G, and V of the spectrum hues in top line.

and from green to violet affect the violet-seeing nerve. Being originally produced from white light they are in proper proportion to affect the three nerves to the necessary amount to give white.

Again, consider where some color rays were obstructed; one or two nerves will be insufficiently stimulated to give white, and the extra stimulation causes the color called the dominant hue.

Every similar problem may be attacked in this way. Take an example of selective absorption. Let white light fall on a body and let some of the rays be *partially* quenched, the others reaching the eye in full measure. Now, as none of the rays are entirely quenched, there will be some to form white light; the remainder affect one or two sensation nerves to give the dominant hue and thereby produce a lightened color.

It is useful, in dealing with such problems, to suppose that all rays in white light are taken as 100 in amount, then, by drawing a line parallel to the base-line of the curve, including an equal amount of all the rays below the curve, a portion will be cut off which will represent the percentage amount of white in the curve. The rest of the curve can be similarly treated to find the dominant hue (Fig. 38).

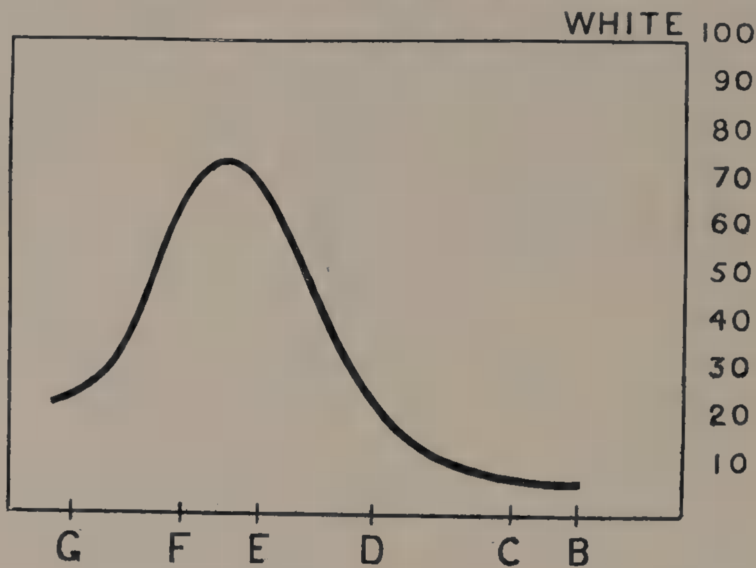

Fig. 38. Color ray composition of emerald green, showing 8 per cent. of white light (Abney).

Then, knowing the dominant hue, the color of the object may be expressed in terms of the three fundamental sensation colors, or their substitutes.

It is quite possible to treat such problems as in mechanics. Thus the dominant hue, due to a collection of rays of different hues, can be found as the resultant in a parallelogram of forces, or by cutting out a curve drawn on paper and finding its centre of gravity. Sometimes it is useful, when the relative areas of the curves are concerned, to cut them out of paper and to weigh them. The planimeter affords the easiest method of ascertaining the areas.

CHAPTER XII.

THE REPRODUCTION COLORS FOR PROJECTION.

The reproduction colors for projection must comply with certain conditions, which are, firstly,

HUE.

Unless the correct hues are chosen for the reproduction colors, some of the spectrum colors cannot be imitated correctly *both in Hue and Purity*. Thus, suppose the green reproduction color is of a bluish shade (incorrect), the others being correct, it will be readily possible to imitate all spectrum colors from this bluish-green to the blue-violet of the spectrum, for the excess of blue-violet nerve stimulation in the green reproduction color can be counterbalanced by the use of less* blue-violet. In attempting to imitate the spectrum hues from red to bluish-green a small amount of white must be formed, because all three sensation nerves must be affected. These hues, therefore, are *paled* by the admixture of white.

[It must be remembered that even when using the (spectrum) hues which are considered the most correct, a certain amount of white must always be stimulated, but this is unavoidable by any means so long as we cannot use the actual sensation colors (page 118). What is referred to above is an amount of *paling* in excess of this amount.]

Similarly, if the other reproduction colors are incorrectly chosen, impurity will result.

Any three simple rays in the spectrum, except the actual complementaries to red, green, and blue, which are widest apart (consider the spectrum as circular), could be used for reproduction colors and give correct hues, but with incorrect purity, as explained above.

In dealing with spectrum experiments it is possible to secure the most correct reproduction colors, but in the practice of color photography (with the exception of Professor Wood's method, where the reproduction hues are secured by an artifice, which is actually spectroscopic, Chap. XXIX.), the colors used are derived from white light by selective absorption. It is not, practically, possible to produce monochromatic light by this means, hence the reproduction colors are neither pure, nor are they always of the exact dominant

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* The *quantity* is varied; it is not necessary that the other reproduction colors should be also altered in hue, which, of course, it is possible to do.

hue required. Now, it is more important to reproduce correctly the hue than to secure the exact luminosity and purity; consequently it will be necessary to modify the curves from which the color filters are constructed. (*Cf.* instrumental means, Chap. XIII. Abney's Three-Color Sensitometer, Chap. XXII.)

THE SECOND CONDITION IS LUMINOSITY.

It is easy to secure the correct relative luminosities of the three reproduction colors by adopting the *convention* that the *mixture of the three hues shall form white.* This is secured in practice by altering the relative widths of slits in the spectroscope, or by using Abney rotating sectors, or by altering the absorptions in the color filters used in the Kromskop or projection lantern. There are, in general, three factors in the luminosity, the white light, the color filter, and the special means for altering the luminosity, such as sectors, diaphragms, or neutral tinted absorbing media, such as patches of developed density.

The absolute value of the luminosity is secured by the amount (brightness) of the white light from which the reproduction colors are made.

THE THIRD CONDITION IS PURITY.

The reproduction hues are represented by very narrow slices of the spectrum giving monochromatic light. Less exclusive or improperly chosen colors give rise to added white, *i.e.,* impurity, and the reproduced colors are therefore paler than they should be (see above, Hue).

Important distinction between "taking" and reproduction colors.

It will be noticed by studying Maxwell's curves that the position of highest ordinate in each curve is not in the position chosen for the reproduction colors. The dominant *hues* of the filters required to use with photographic plates and the *hues* of the reproduction colors are then quite different. The ray compositions of the two sets of screens are also opposed, for in the case of the reproduction colors only very *narrow bands* in the spectrum are required, whereas each "taking" screen must pass all those rays which affect the particular sensation nerve. Thus, collectively, the "taking" screens pass *all the rays* of the spectrum.

(For the relative amounts of the respective reproduction colors required to reproduce the spectrum see diagram and description, pages 117 and 118.

CHAPTER XIII.

SIMPLE APPARATUS FOR EXPERIMENT.

The experiments, detailed in previous chapters, made by means of the hues emerging from slits placed in the focussed spectrum can be also made by apparatus much less complicated and expensive.

In the actual production of the positive in colors by synthetical methods, the pure colors (spectrum colors) are not easily obtainable, and, in their stead, a near approach, in the light coming through colored glasses, is used. Colored glasses are chosen which pass rays approximating to the narrow bands in the spectrum which they respectively represent. Such is the method adopted by Mr. Ives in the Kromskop and projection lantern.

To secure the combination of the colors a great many devices are available, requiring more or less apparatus. The following is as simple as any. All that are required are an even flame of large dimensions, such as is given by a Welsbach incandescent mantle, a lens of, say, three inches diameter, and three pieces of glass—red, green, and blue-violet. These are laid in a line, on a piece of cardboard, which has holes cut out to allow three beams to pass through. The lens is fixed against an aperture in a box, which should be blackened inside, and the image of the mantle is received on a small white surface inside the box. Focus the mantle, and insert the glasses on their cardboard against the lens, and if the three apertures are correctly adjusted in size a white image is obtained. By covering up the apertures, singly and in parts, the six main divisions of color can be shown. Graduated wedges made on dry plates can be used to produce intermediate tints.

This experiment requires so little apparatus, only a uniform light and a common lens, such as a reading magnifier, that any one can perform it. Pieces of glass of representative colors can be procured from a glass dealer,* and strips of negative with varying densities can be used to vary the light. The box should have an eyehole in the lid or side, and the image should be received on a white screen, such as a piece of visiting card ¼ in. square, placed on a projecting pyramid of cork which is attached to the inside of the box. The white screen should be smaller than the image so that the edges of the flame are not visible.

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* It is notable that the red, green, and blue glasses procurable in shops are very nearly the hues required. This assists in making the choice.

If desired, the glasses may be increased in number to make the rays more monochromatic: the selection used in the Kromskop is very suitable. A simple test for this is to overlap them in pairs and look at a bright light, to which they should be opaque. (See Fig. 39.)

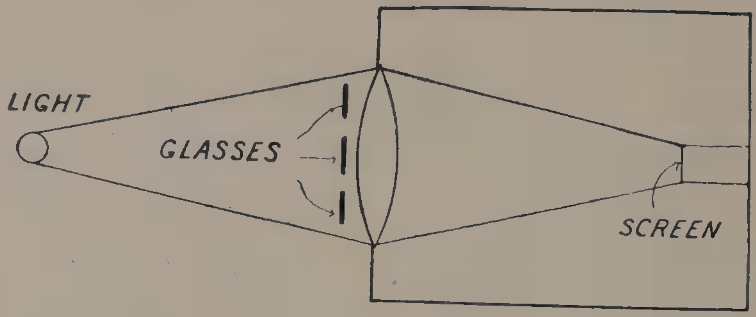

Fig. 39. Simple means of combining three Colored Lights.

General utility of this apparatus.

This little piece of apparatus, which resembles the means adopted by Captain Abney to recombine spectrum rays, should become of general utility in color work. It will enable hues to be combined in measured proportions in order to match colors whose hue values, in terms of three colors, it is required to know (see Chap. XXII., on testing color filters). If its reproduction colors are of the exact hue of the correct spectrum colors it will enable us to find the value of the reproduction colors used in the Kromskop, etc., or employed in color printing, and from these the Maxwell curves can be corrected. Such an instrument would be a constructive or synthetical tintometer (similar to Mr. Lovibond's tintometer), and would take the place of that instrument, besides being of great use for its particular purpose, namely, *matching a color by mixtures of three chosen hues.* The design of the instrument is capable of many modifications, but the above sketch gives the simplest and readiest means.

CHAPTER XIV.

THE REPRODUCTION COLORS FOR PRINTING.

The various colors of the spectrum and the composite colors of nature are counterfeited by the three reproduction colors, red, green, and blue, by the addition of colored light to colored light. Thus, the elementary colors are due to the colored lights separately; other colors are made by mixtures of these; white by the addition of all three, and black by their suppression. The colors are superposed on a white, but otherwise unilluminated, screen; that is, one capable of reflecting all three rays.

The method of adding colored light to colored light is not the only way in which the various colors can be formed. *It is possible to start with a surface reflecting white light, and to print on to it three* transparent *pigmentary reproduction colors, which, separately or by mixing in proper proportions, shall successively absorb the rays reflected from the white paper producing color.* (Chap. V.)

This, of course, is no novel fact, it being common knowledge that three pigments would *approximately* reproduce all others. It remains, then, to discover how this can be done to reproduce *all* colors in correct hue, luminosity, and purity, and what the hues of the pigment colors and their color-ray compositions must be.

It will be found that the relationship of one method to the other is very simple, provided certain conditions are adhered to.

The subject may be approached in the following way:

Imagine that a triple lantern is used to throw the three-colored lights on to a white screen. (Fig. 40.) Let, first, all three lights be superposed, producing white. If a positive is now placed in one of the lanterns its opaque parts stop the light, and the hitherto white light is now colored by the other two lights, that is, by the complementary color; thus, if the red positive be opaque then the complementary color, blue-green, is seen (see page 97).

The opaque part of the positive must be regarded as stopping its own color (red), and giving rise to its complementary (blue), while the transparent parts of the positive still give white.

If, now, the positive could have the silver, of which its shadows are composed, converted into a blue pigment reflecting green and violet, while the transparent parts remain white or colorless, then the same color will result when the positive is viewed by white light (made by the three colored lights).

Similarly, the other positives must have their silver converted into the complementary colored pigment.

The diagram will assist in explaining this.

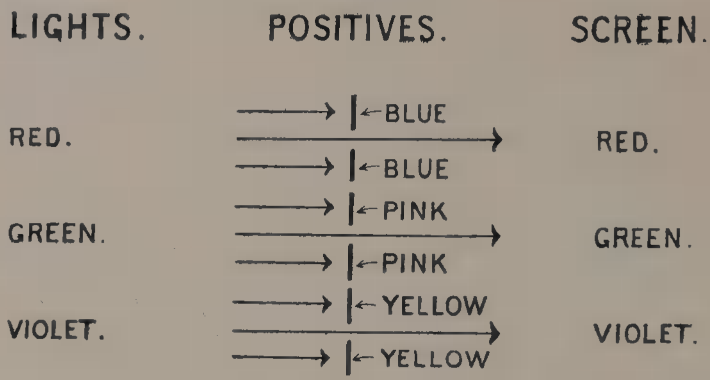

Fig. 40. To take the place of an actual demonstration with a three-color lantern.

The short vertical lines represent the opaque parts of the positives, and the long and short arrows represent light respectively transmitted and absorbed.

We see from this that when pigments are used the hues of the positives made from the negatives must be complementary to those which the negatives represent. Thus the positive from the red record negative should be made in blue. It is immaterial whether the pigment be in the glass or whether it be spread on paper so long as the light passes through; therefore the hues of the pigmentary printing colors are known from the above. They are for the red record negative a greenish-blue, for the green negative a purple, and for the violet negative a yellow.

An Alternative Explanation.

It is helpful to consider this subject from a slightly different standpoint.

A black and white subject consists of two parts, complementary to one another, which are white paper for one part, and white paper covered with black pigment for the other part. This black pigment absorbs the light from the paper, and so it may be regarded as a (—) white, or a white absorption pigment (see page 98).

A negative of these two parts of the subject will also consist of two complementary parts, respectively opaque and transparent, the opaque parts corresponding to where the light has acted, and the transparent portions corresponding to where the absorption of the light from the white paper by the black pigment has taken place in the original subject.

In making a print from such a negative, the materials are white

paper and white absorption pigment (— white, or black). The transparent portions of the negative print this pigment, while the opaque portions have no *active* part in producing the print. Thus it may be said that the negative is made by white, but prints in black, *i.e.,* the complementary color. In printing, therefore, from negatives the ink is complementary to the part of the object which photographs.

Were such a subject reproduced by a projection method (lantern slide), then the transparent portions of the negative (through the aid of a transparency made from the negative) will be again represented by black on the screen, and to the opaque parts (likewise by aid of a transparency) will correspond the white. Thus the same portions of the negative will be represented in the two images by similar light or shade, though the two methods of producing the images are exactly opposite to one another in character (complementary). The same negative may be used for both methods of producing the image.

Next, apply similar reasoning to the case of the reproduction of colored subjects.

To the opaque and transparent portions of the color-record negative must correspond complementary hues. Thus, in a negative whose opacity is caused by rays which affect the red sensation nerves, the transparent portions will represent (—) red, and, as it is the transparent portions which print, the ink used in printing from this negative must be of a (—) red hue.

The red recording negative will, therefore, print in (—) red, or a red absorbing pigment, that is, one which reflects green and blue.

The green recording negative will print in (—) green, or a green absorbing pigment, that is, one which reflects red and violet.

The blue recording negative will print in (—) blue, or a blue absorbing pigment, that is, one which reflects red and green.

Conversely, if a negative (by its transparent portions) is to print in a (—) red ink, its opacity must be due to red rays. (See page 164.)

How the Colors are Reproduced.

Consider, first, the reproduction colors themselves, blue, yellow, and pink. Take, for example, a blue patch on a white ground.

The red record negative will be made opaque by those portions of the subject reflecting red light. Thus, the white paper* will cause opacity. The blue pigment, not reflecting red, is represented in the negative by transparency. This negative is printed in (—) red, and so the blue patch and white paper are reproduced.

The green record negative is made opaque by the green rays reflected both from the white paper* and the blue pigment. In this

* It must be remembered that white paper reflects a full amount of every color, and therefore should give the same opacity as a red, green, or violet patch.

particular subject it has no transparent portions, and therefore does not print.

The violet record negative is made opaque by the violet rays reflected both from the white paper* and the blue pigment. In this particular subject it has no transparent portions, and therefore does not print.

A yellow or pink patch may be treated in a similar manner. (Fig. 41.)

These results may be expressed in tabular form, thus:

Photograph	red,	print in	(—)	red, or blue
"	green,	" "	(—)	green, or pink
"	violet,	" "	(—)	violet, or yellow

Next, consider how a red, green, or violet patch is reproduced.

Take, for example, a green patch on white paper. A green pigment is a red and violet absorbing pigment.

In the red record negative the white paper* will be represented by opacity. The green patch is represented by transparency. This negative prints in (—) red, therefore the green patch is represented, in the print, by blue, or red absorption pigment.

In the green record negative both the white paper* and the green patch are represented by opacity.

In the violet record negative the white paper* is represented by opacity, and the green patch by transparency. This negative prints in (—) violet, therefore the green patch is represented in the print by yellow, or violet absorption pigment.

In all three negatives the white paper is represented by opacity.

Therefore, in the print the white paper photographed is reproduced by the white paper on which the print is made. The green patch is reproduced by the superposition of the red absorption and violet absorption pigments. Thus, the two superposed pigments cause absorption of all the rays reflected from the white paper except the green, which remains to reproduce the original patch of green pigment.

A green or violet patch may be treated in a similar manner (Fig. 41). (See also pages 103 and 104.)

These results also may be expressed in tabular form, thus:

Regarding the action on the negatives as combined,

Photograph (red + green), or yellow, print in (—) (red + green), or violet.

" (red + violet), or pink, print in (—) (red + violet), or green.

" (green + violet), or blue, print in (—) (green + violet), or red.

" (red + green + violet), or white, by the three negatives, and print in (—) (red + green + violet), or O, that is, nothing is printed.

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* See footnote, page 129.

A black patch is represented in all three negatives by transparency, and in the print by the mutual absorptions caused by the superposition of the three printing inks (Fig. 41).

A table is given in the following Fig. 41 which shows how the colors are produced.

Hues intermediate to the six already considered are produced by intermediate *amounts* of pigment.

Color of Object Photographed.	Negatives R G V	Projection Transparencies R G V	Reproduction colors used in Projection	Printing inks laid down	Color stopped by ink	Color Resulting
White	O O O	T T T	R G V	— — —	—	White
Black	T T T	O O O	— — —	B P Y	R G V	Black
Red	O T T	T O O	R — —	— P Y	Blue	Red
Yellow	O O T	T T O	R G —	— — Y	Violet	Yellow
Green	T O T	O T O	— G —	B — Y	Pink	Green
Blue	T O O	O T T	— G V	B — —	Red	Blue
Violet	T T O	O O T	— — V	B P —	Yellow	Violet
Purple	O T O	T O T	R — V	— P —	Green	Purple

O means Opaque, and T means Transparent.

Fig. 41.

Variations in the brightness of the hues are produced by varying the amounts of pigment.

Lightened hues (page 111) are produced by decreasing the amount of absorption, namely, by using less pigment.

Degraded hues (page 111) are produced by increasing the total amount of absorption, namely, by using some of all three pigments.

Thus, any hue, in any shade desired, can be produced by three pigmentary reproduction colors.

Quantitative application to all Spectrum Colors.

What was done on page 116, Fig. 35, for the reproduction colors for projection may now be done for the reproduction colors for printing. Curves showing the amount of each reproduction color required in imitating the spectrum colors could be drawn (page 132). In doing this the method by which the colors are obtained by pigmentary mixtures must be taken into account. The amounts of the reproduction colors required would then have to be ascertained from experimental mixtures, and not deduced from experiments made in mixing projection colors (pages 130 and 131).

Hypothetical conditions.

It must be remembered that there are certain conditions under which we are supposed to be regarding the pigment.

In the first place the white light in which the pigments are viewed is supposed to be composed only of red, green, and violet lights, and these, therefore, are the rays the white paper reflects. Secondly, the pigments used are supposed to reflect two of the three lights and stop one.

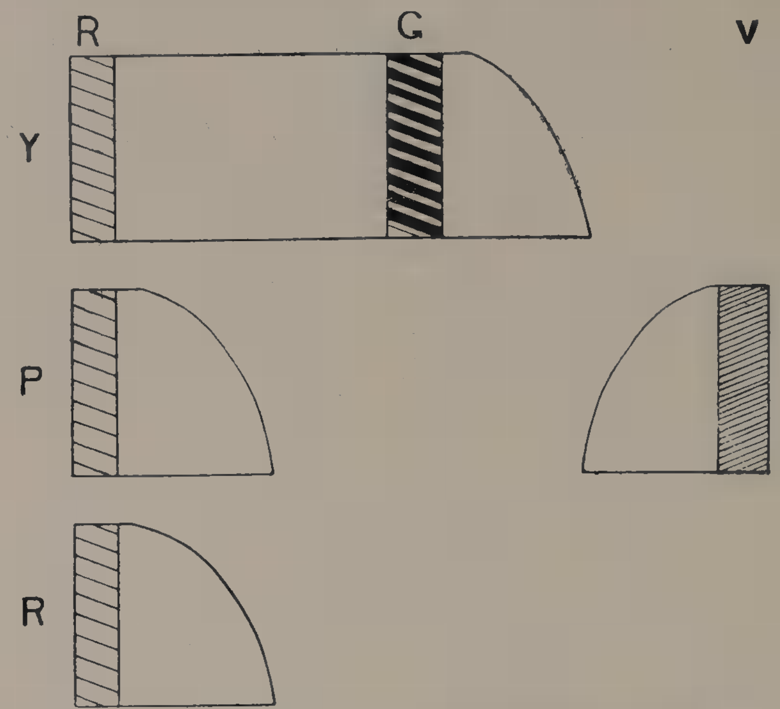

Fig. 42. Color ray composition of yellow and pink pigments, showing the reflected rays.

Under such circumstances, the results, though correct, would be useless, on account of the low illumination, for the white, instead of being composed of all the colored rays, would only be composed of the three narrow bands, and similarly the colored pigments would lack brightness.

Practical conditions. Color ray composition of pigments. Further research needed.

To secure more brilliant illumination, and to employ unshielded daylight and other natural lights, would require that all the rays of daylight should be reflected from the paper to make white, and that the pigments should each reflect more rays than the two narrow bands of the spectrum. Consequently, a pigment should reflect all rays except those which affect the record negative it represents. A

yellow pigment, therefore, must reflect spectrum rays from the red to the blue, absorbing the violet. It appears, however, for reasons which cannot be discussed here, that even such a color ray composition is not quite perfect, and that a compromise must be made. Mr. Ives, who stated the hue and ray composition of the printing colors for use in ordinary daylight, proposed to use pigments which absorbed *completely* rays which *chiefly* affected only one record negative (see *British Journal of Photography*, Vol. 38, 1891, page 140).

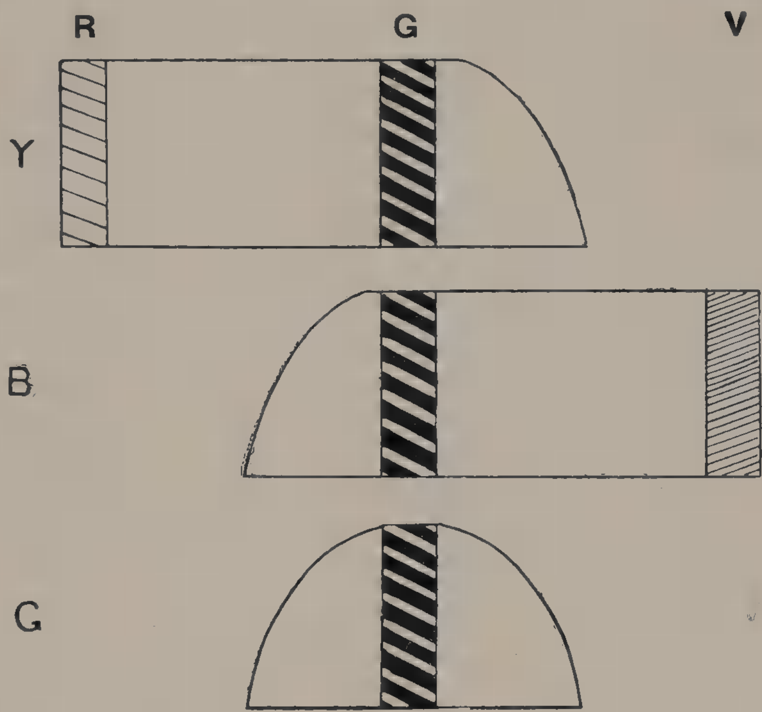

Fig. 43. Color ray composition of yellow and blue pigments, showing the reflected rays.

These ray compositions, which will correspond to *very wide slits*, could be represented by replacing the curved portions of Figs. 42, 43, and 44 by vertical lines. The exact portions of these limiting lines should be such that the minus parts of the rectangle, respectively red, green, and violet absorbing, should, when added together, comprise the whole rectangle.

These alterations of the ray compositions of the pigments to suit the practical conditions will introduce changes which will make the above statements incorrect.

It will be interesting to note that it does not seem certain that correct three-color printing in pigments is, or ever will be, possible. By correct is meant correct in hue, luminosity, and purity.

Further information is required as to the color ray composition of the theoretical pigments. The two limits only are fixed at present: these are a ray composition of only two narrow slits corresponding to

the hypothetical pigments considered above, and a practical ray composition comprising the whole rectangle except a narrow slit of complementary color.

By the superposition of these (modified) reproduction pigments the other colors are produced in a nearly similar manner as before. The same diagrams, which are quite arbitrary, may be used to illustrate both cases. One set of figures represents a patch of yellow laid over a patch of pink in the full relative proportions. The rays com-

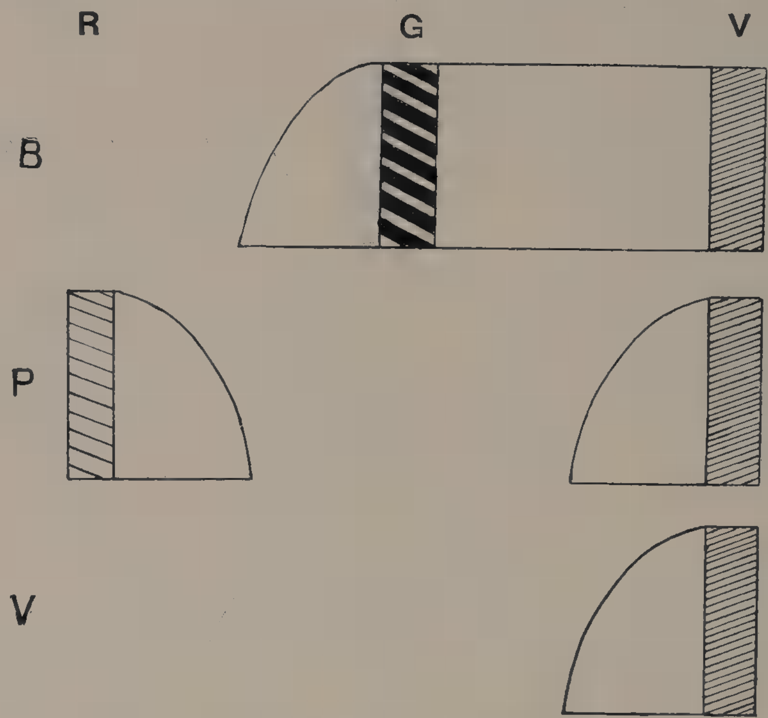

Fig. 44. Color ray composition of blue and pink pigments, showing the reflected rays.

mon to both are those shown in the figure on page 133. Figs. 42, 43, and 44.

The narrow bands of color in the theoretical pigments are shown by the blocked-in narrow bands.

By using the colors in various proportions intermediate colors result.

Reproduction of Spectrum by pigments.

We may now consider how the spectrum would be rendered by pigments (see also above, Fig. 35).

We require suitable pigmentary color mixture curves drawn to such a scale that equal heights of ordinate give white. By surrounding this by a parallelogram we may picture that the space within each curve, separately, is the *deposit* on the negative, and that

the remainder of the parallelogram is what is *printed* by the negative. They are complementary parts, negative and positive.

Let the figures represent the curves, each of which is supposed to be converted into opacity in the respective color record negative. (Fig. 45.)

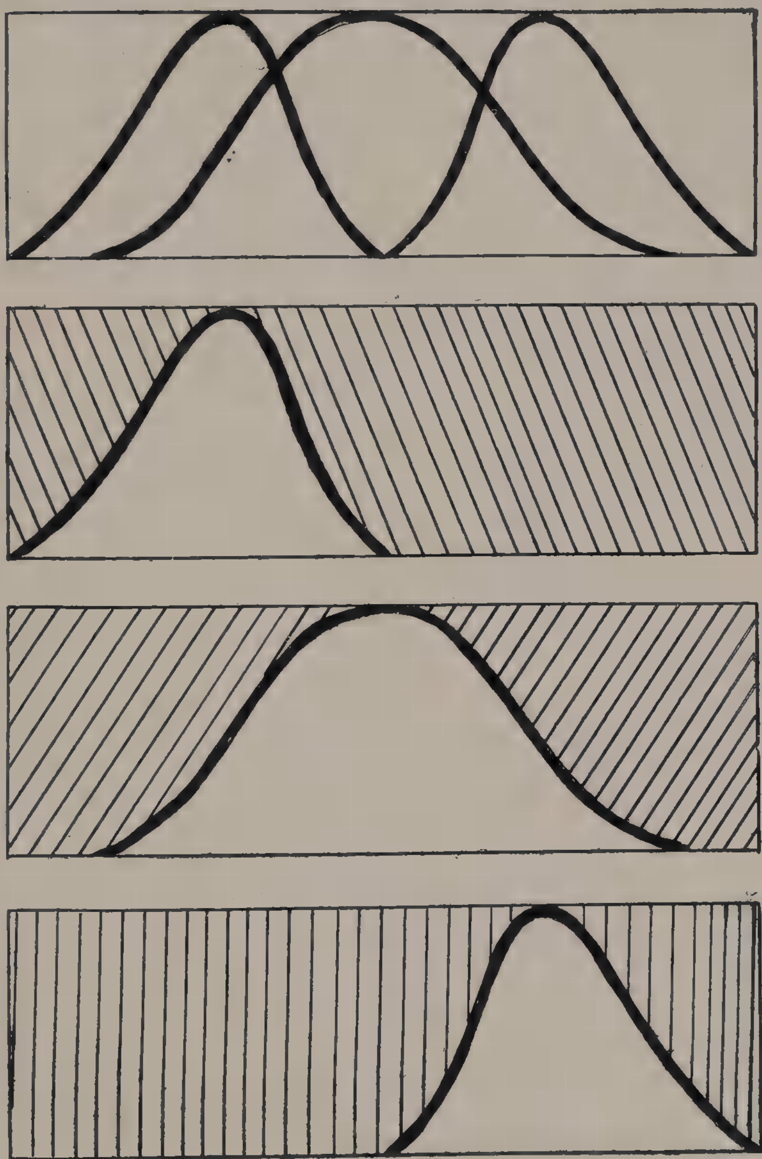

Fig. 45. Color mixture curves (top). Three separate positives showing distribution of colored inks in reproducing the spectrum. See key on next page.

Round each curve fill in with the color which the negative prints.

These three prints, respectively in pink, blue, and yellow, are to be superposed to give a three-color representation of the spectrum. (Fig. 46.)

It should be remembered that this diagram is quite distinct from the diagrams of the color ray composition of the pigments, though they may be somewhat similar in form.

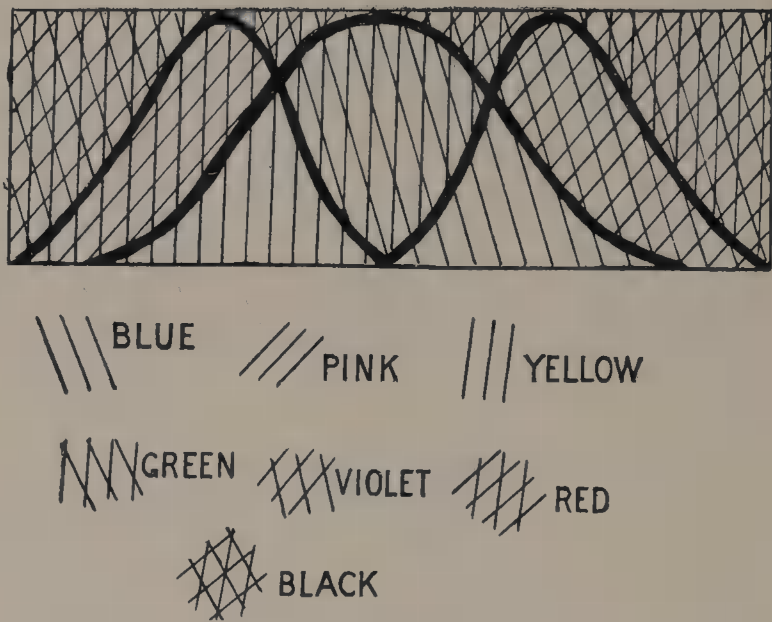

Fig. 46. Spectrum reproduced by the superposition of the colored positives (and key).

The Color Constants.

As with the reproduction colors for projection, the three-color constants, hue, luminosity, and purity, are involved in the pigmentary colors.

The hues for the printing colors are readily found. They are, in both the hypothetical and practical cases considered, the complementaries of the dominant hues of those rays which produce opacity in the negatives. In the hypothetical case they are also the complementary (or minus) colors to those employed for projection.

What was detailed in Chap. XII. also applies in the present case. Incorrectness of dominant hue in the printing colors will lead to incorrectness in purity in the reproduction, but instead of being *paled*, the mixture of pigments will give *degraded hues* (page 111).

The relative luminosities and purities of the three pigments are not so readily obtained as with projection colors. The three pigments must be of correct *relative* luminosity, and this must be due to the spectrum rays which they transmit, and not to any added opaque white or black pigment, also the three pigments must bear a definite relation to white.

Regard *white* paper as reflecting the whole of the (visible) spectrum rays, then, of these, a *definite proportion* is used to form the pink, yellow, and blue reproduction pigments respectively. Thus it

is possible to state in definite terms what are the luminosities, relative to themselves, and relative to white.

To fulfil these conditions the color ray compositions of the theoretical pigments require to be exactly determined, and then the nearest approach to the theoretical conditions found in actual pigments.

The primary controlling factor in luminosity is the white paper to be used as the support for the pigments (page 124).

For convenience it is common practice to adjust the relative luminosities of the pigments so that the deepest shade produced by the mixture of all three shall be black or without color.

The luminosities of the colors produced by the mixture of pigments also bear definite relationships to the reproduction colors.

Departures from Theoretical Conditions.

There are certain adventitious effects arising from the mechanical mixture of pigments, which, from not being considered in their true light, are looked upon as failures in the theory. One of the most important of these is lack of transparency.

The definitions that have been given of the requirements in pigmentary reproduction colors state that the pigments are employed to absorb certain rays scattered from the white paper, and to reflect the others either directly to the eye or after being still further robbed of some of their constituents. If, as generally happens, one of the pigments, viz., the yellow, is opaque, then this condition cannot be obtained, and different results will follow according to the order of printing. If the yellow were perfectly opaque, then, if it were printed last, the pigments on which it was superposed would have no effect in modifying its color; it, as it were, carries its own white paper with it, and this is interposed between it and the other pigments; when printed last, therefore, it gives its own color. If, however, the opaque yellow is printed first, it absorbs violet and reflects the spectrum rays from pink (*i.e.*, the dual rays, red and violet) to blue, which are utilized in forming the reds, yellows, greens, and green-blues. Even when printed first it has a harmful effect, because an opaque pigment is not altered in brightness by variation in thickness of deposit. The transparency can be roughly tested by printing on black paper.

Optical Contact.

In this connection it is interesting to note that unless the three printing colors are in *optical contact,* a difference in color is produced according to which side of the transparency (triple superposed colored films on a transparent support are meant here) is toward the observer, and according to the amount of diffused light falling on the same side. This effect, though small in amount, is quite noticeable.

Variation of Color by Thickness.

Another so-called failure is caused by the variation in color due to varying thickness of pigment.

In general, the dominant hue of a pigment is changed by altering the thickness of layer of the pigment through which the light passes. This is due to partial absorptions in the pigment (page 102).

Pigments of a purple hue, also some greens reflected in a narrow band of red, show this defect well.

The subject of pigments, in their optical, chemical, and mechanical aspects, is a large one, and the student should consult works on that subject.

In typographic printing the printed ink-dots may or may not be exactly superposed. It will be seen, however, if the pigments fulfil the requirement of transparency that the same color effect is produced in each case, but this is on the supposition of the use of the hypothetical pigments.

Instrumental means.

The apparatus described on page 49 can be used to find the hues of the pigments in terms of three standard reproduction hues. On account of the accidental effects which arise when mixing pigments it is not easily possible to foretell what the luminosity and hue and purity of the derived colors will be. It would appear that actual mixtures of the pigments in different proportions would need to be made, and from these, after measurement, modified curves might be drawn. (Page 130.)

CHAPTER XV.

THE PHOTOGRAPHIC PARALLEL.

Referring to pages 121 and 122, we recall that on the three fundamental-color-sensation theory, all colors produce their visual effects by the stimulation of one, two, or three of the fundamental color sensation nerves; also, on page 119, the distinction that was made between the unrealizable fundamental color sensations and the spectrum colors which are the nearest approach to them, and which are substituted for them. From what has gone before it will be gathered that in practical three-color work we are independent of the theory of color vision, etc. We do not seek to enquire to what extent colors affect the three color-seeing nerves, but rather to find out practically in what degree the three reproduction hues are required to equal (visually) the color to be reproduced.

There remains now, in order to employ photography for the permanent records of the fleeting impressions produced on the retina, that the photographic plate should be capable of registering the color effect, referred to three primary colors, according to the degree shown in Maxwell's curves. Thus the photographic plate should be stimulated to "opacity" by color in the same degree (corrected value) that the color-seeing organ is stimulated to color vision.

We require next that, when photographing the spectrum, patches of density should be formed on the negatives, whose opacities should correspond with the amounts of stimulation of the respective sensation nerves to the degree shown in Maxwell's curves.

We need next to find a suitable photographic plate, and means to ensure that it is affected to the proper degree. This will be the subject of the third division.

DIVISION III.

THE NEGATIVE.

THE EMPLOYMENT OF PHOTOGRAPHY TO MAKE THE COLOR RECORDS.

CHAPTER XVI.

SELECTION OF A COLOR SENSITIVE PLATE, AND TESTING THE COLOR SENSITIVENESS.

Colors are the *visual* impressions caused by light of definite wave-lengths. They have no objective reality, but are a creation of the nervous system. Photographic plates are not sensitive to color as color, but only to the definite vibration to which the color is referred. Now, the eye is sensitive to wave-lengths of light from the red to the violet, and it is necessary, therefore, that the plates also should be sensitive within these limits. The range of sensitiveness of the eye from red to violet is practically one octave (vibration frequencies 395 billions to 763 billions, or nearly double). The total range of photographic plates, prepared in different ways, is about fifteen octaves, from infra-red (Abney's experiments) to ultra-violet (Schumann). The plates in ordinary use are sensitive only in a small degree to the less refrangible rays (red), the maximum of sensitiveness being in the blue, violet, and ultra-violet. It will be noticed, therefore, that the range of visual impressions and the range of photographic activity of ordinary plates have little in common.

Orthochromatic plates.

For ordinary purposes plates are required sensitive to colored rays in accordance with their luminosities, *i.e.*, to their intensity of visual impression (see page 106). This desideratum has only been partially effected. The previous disabilities of being only sensitive to blue, violet, and the useless (for ordinary purposes) ultra-violet

have been removed (this discovery by Dr. Vogel dates from 1873), and plates are now prepared commercially which are sensitive from end to end of the visible spectrum, from red to violet. The sensitiveness is, however, vastly inferior in some sections of the spectrum to what is required in order to render colors in their proper luminosities; the orthochromatism is only *partially* effected. To be perfectly orthochromatic the plates should be sensitive to the colors of the visible spectrum, and *these only*, and in *measure* according to the *luminosities* of the colors (see Abney's diagram of luminosities, "Action of Light in Photography"). Rapid plates of the ordinary kind have been shown to be sensitive to the longer wave-lengths (red, orange, yellow, green), but the differences in sensitiveness, and exposure entailed, between the two ends of the spectrum are enormous. A noticeable feature in these plates is that the sensitiveness is continuous throughout the spectrum, whereas plates specially sensitized have the additional sensitiveness added in bands.

Requirements in plates for Three-Color Work.

It is advisable, and for good work absolutely necessary, that all three exposures should be made on one kind of plate, and a reference to Maxwell's curves will show what is required in a plate suitable to photograph each section. Imagine each of the curves of the same height, and it will be noticed that the curve of sensitiveness requires to be fairly even along the middle of the spectrum, sloping down at the ends (like an inverted pie-dish). The plates might, of course, have three maxima, but the sensitiveness in between should be considerable, not zero, on account of the overlapping. This is quite distinct from the curve of luminosities, or the curve of a perfectly orthochromatic plate; such an orthochromatic plate would not therefore be required.

Use of separate plates.

Separate plates might, also, for this purpose, be sensitized in accordance with the curves, thus avoiding the use of color filters. It appears, however, that the plates thus sensitized differently, though identical in their properties before orthochromatizing, possess different properties afterwards. These differences of behavior render the use of such plates impossible for correct work (see page 172). Employing different plates, the series A and series B of Lumière and an ordinary plate are suitable. The speeds of these may vary as the table shows, but this is not detrimental. The development factors (Hurter and Driffield) vary somewhat, and it is this which makes it difficult to use different plates (see later, Chap. xxiv.). The range of correct representation is another quality to be reckoned with.

Lumière A	Speed	42	Development Factor	1.6
" B	"	40	" "	1.48
Castle (ordinary)	"	39	" "	1.6

(These are relative speed numbers.)

Testing color-sensitive plates.

There are several color-sensitive plates upon the market, all showing a large increase of sensitiveness to the warmer colors over the ordinary plates. In some the sensitiveness extends to the end of the red, and in others to the yellow only. Sir W. Abney has measured the different brands, and finds that none of them possess a regular curve of sensitiveness. The effect of dyeing, which renders them more sensitive to certain colors, is of a local nature, and photographs of the spectrum taken on them show, on measurement, very irregular curves. This may be illustrated by exposing an orthochromatic plate to the spectrum. Little is gained by one negative only, but by giving such an exposure at first as only to show action in the most active part of the spectrum, then making other photographs, doubling or trebling the exposure, and so on, when other portions of the spectrum affect the plate, a partially quantitative test can be made. Unless carefully made, photographs of the spectrum to show the distribution of color sensitiveness are of little use. Even comparative results can be misleading on account of the difficulty of judging density.* To make a proper test the densities should be measured photometrically, and referred to a scale of densities made by known quantities of light.

Plates under experiment should be treated exactly alike as regards development to make the results comparable. The constitution of the developer, its temperature, and its concentration should be the same for all.

Gaps in the color sensitiveness.

The diagrams given by Sir W. Abney from his measurements of Cadett's spectrum plates and of Lumière's red-yellow sensitive plate show how impossible it is to secure *perfect* orthochromatic renderings of the spectrum, for no screen could give the extra exposure required in *all* the hollows of the curves. It does not follow, however, as Abney has pointed out, that such a state of things, though unfortunate, debars such plates from being used for orthochromatic and three-color photography, and for the following reasons.

Heterogeneity of color beams in Nature.

In the previous demonstrations with the spectrum (Chap. III.) it was shown that a color, though apparently simple to the unaided

* No negative of the spectrum should be denser than will print on paper. All results should be compared as prints.

eye, could be analyzed into a large number of constituent rays. Thus, a pink color might consist of all the rays of the spectrum except a few in the green. Now the color composition of natural objects is of the same heterogeneous nature (except in a few instances, such as colored light from a diamond or mother of pearl, etc., where a sorting out of the color rays has taken place). A yellow color might be effectively rendered by a plate insensitive to spectrum yellow, on account of its red, orange, and green rays, supposing the plate sensitive to these rays. For this and other minor reasons, such as convenience, the spectrum test* is not so generally useful and convenient as one invented by Sir W. Abney and called by him *a color sensitometer* (see *The Photographic Journal*, Vol. xix., No. 10, June 29, 1895). The original paper should be consulted, but it is hoped that the following will give sufficient details of the working. (See also "Color Correct rendering in Monochrome." Photography, Vol. xi., No. 548.)

Abney's Color Sensitometer for Orthochromatism.

Instead of exposing the sensitive plate on trial to the action of homogeneous beams of colored light (such as given by the spectrum), when, on account of the "gaps" of color sensitiveness, some colors might entirely fail to give action on the plate, and so give misleading quantitative results, advantage is taken of the fact that colors in nature are *rarely*** of a homogeneous kind, and the plate is tested by exposing it to white light filtered through colored glasses. These colored glasses can be selected to pass only certain regions of the spectrum which can be narrowed as much as desired by the use of suitable glass or glasses; glasses giving as many different hues as are required can be combined into the sensitometer. The plate under trial is exposed under the colored glasses, and, after development, examined for relative deposit in the various squares.

The deposits on the negative should be proportional to the brightness of the various squares of colored glass. It would, of course, be troublesome to measure these opacities on every negative, and, again, the absolute value of these opacities would depend upon the amount of development. The preferable plan is the one devised

* The spectrum test is useful to tell to what parts of the spectrum the plate is sensitive; that is a purely qualitative test. Such a test can be made in a comparatively inexpensive photo-spectroscope, constructed without moving parts. A single prism of Iceland Spar (transparent to visible and invisible violet) and uncorrected quartz lenses are very useful to determine the presence of ultra-violet. For the quantitative test the Abney Color Sensitometer is the most useful apparatus.

** "Rarely" used here means that in some cases there might be exception; one case is obviously the spectrum itself. Thus the Cadett orthochromatic plate and screen, though rendering the colors of natural objects perfectly, would not behave so well on the spectrum. If a plate is satisfactory in regard to color rendering when tried on the spectrum it must be satisfactory when tried on natural bodies.

by Abney, which makes this method of testing plates for color readily workable. The squares of colored glass are measured in a photometer for transparency, then a rotating sector with portions of the disc removed, or patches of developed density are placed over the squares, and so arranged that the transparencies of all the squares are made equal visually. (Were the spectrum convenient to use, a similar artifice could be adopted in the form of a revolving template.) The amount of light passed by all the squares being now equal, the resulting opacities on the sensitive plate after development, *if the plate be perfectly orthochromatic,* will be equal, for to equal amounts of light will correspond equal opacities. It is, of course, an easy matter to observe when the opacities are equal.

The primary object for which this small piece of apparatus was intended was to give a ready means for adjusting color screens to use with sensitive plates (orthochromatic or otherwise).

Uses of Abney's Color Sensitometer in Three-Color Work.

It may obviously be used, when selecting a color sensitive plate, to *test the distribution of color sensitiveness* in the plate, or, when the plate is decided upon, to help in the *adjustment of color screens,* or the *checking of batches* of color sensitive plates for *constancy* of color distribution. Besides, the tests for distribution of color sensitiveness, a test may also be made of *speed,* as it is necessary to have rapid plates to shorten exposures. This test is not the same as the test for general sensitiveness as conducted by the usual methods, but requires to be made under the conditions of illuminant and color filters employed in actual work, and therefore tests must be made for each of the three negatives.

Mr. Cadett has devised a simple modification of Abney's color sensitometer, which is useful for these checking purposes. It consists of a box in one side of which are three apertures covered by glasses representing approximately monochromatic patches of the spectrum, red, green, and blue. A uniform light, diffused by ground glass, passes through the glasses on to a photographic plate. The relative apertures of the three glasses are regulated by wedges until, on trial, equal deposits are given by light passing through the three glasses respectively.

For curves of plates, consult Abney's "Light in Photography." Also Ives, April, 1896, Vol. xx., No. 8, "The Photographic Journal," and Sanger Shepherd, July, 1898, Vol. xxii., No. 2, "The Photographic Journal."

Another important point in the testing of plates is the fidelity of reproduction by the plate under certain conditions. Thus, suppose the plate to be impressed with a series of exposures, each doubling the previous one, thus, 1, 2, 4, 8, 16, 32, 64, 128 units, the resulting opacities may or may not be proportional, possibly the middle gradations will be correct while the opacities of the lesser exposed

patches will be too great, and the opacities of the most exposed too little. If a straight line represent the correct reproduction of a series of tones by opacities in the negative, an effect, as instanced above, may be represented by a curved line, thus, Fig 47 (see also Fig. 50).

See Hurter and Driffield—original paper (Journal of the Society of Chemical Industry, May 31, 1890).

See Hurter and Driffield—later paper (" The latent image and its development ")—Photographic Journal, 1898.

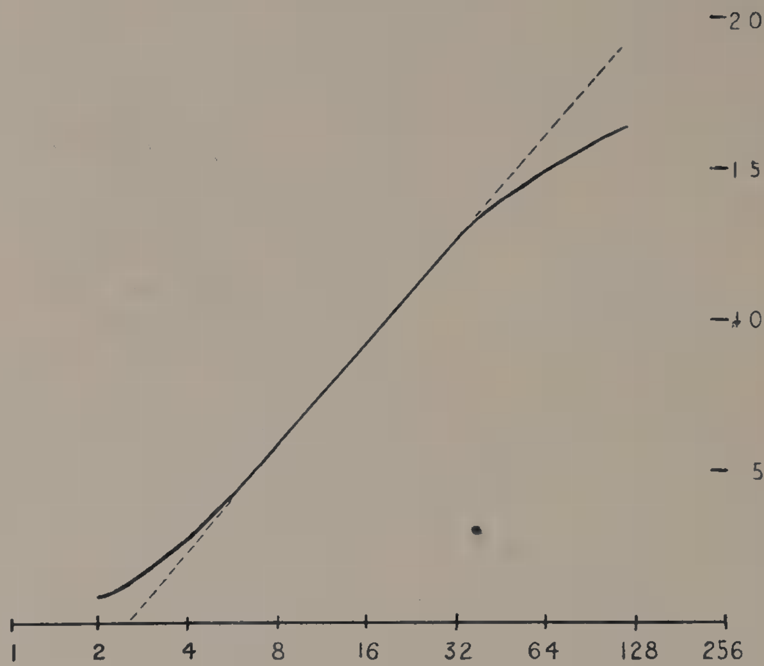

Fig. 47. Fidelity of Reproduction (Negative).

The subject may be best studied by the method of Messrs. Hurter and Driffield. A comparative test, sufficiently good for practical purposes, may be made by taking a scale of tones each tint of which halves the light transmitted. Such a scale of tints should be placed upon the plate and an exposure made (as in making lantern slides), and the plate developed until the ratio of opacities is approximately the same as in an ordinary negative. Upon examination of the plate the various light intensities between these limits should be differentiated evenly from end to end of the scale. It will probably be found that there is distinctness in the middle range, but at each end the opacities merge into one another. (See Fig. 50, *e.*)

CHAPTER XVII.

COLOR SCREENS OR FILTERS.

In the case of the eye it may be supposed that the seeing apparatus is capable of being affected by the various color rays in degree according to Abney's curves, and this without the aid of any extraneous means of color selection.

The photographic plates as at present made have not their color sensitiveness distributed in the same way, and, in consequence, require to have the action of some rays reduced relatively to others. Maxwell's curves state that for the red record negative, for instance, the action must be greatest where the orange and yellow rays act and less in the green and red. It may be taken that the plate used is most sensitive to blue rays, or to invisible rays beyond the blue; a color filter must, therefore, be used opaque to those rays which are not required to act, namely, the ultra-violet rays, and more or less transparent to those which are to produce the desired result.

There are three purposes to be fulfilled by the color filters, viz.:

1st. To cut off *entirely* rays not utilized, namely, the ultra-violet.

2d. To reduce *entirely* rays not required in the particular negative, and *partially* those rays which are required to act only partially.

3d. To do this without reducing the luminosities of those rays which are required to act fully.

The first requirement is discussed in the next chapter. The second requirement supposes that the color sensitiveness of the plate has not been so modified that the use of color filters has been avoided. Different makes of plates require, of course, different color filters, and in all cases the filters must be adjusted to suit the plates. The third requirement affects speed. It means that some rays should be transmitted by the filter without absorption, thus the ray that the filter transmits most freely should suffer *no* absorption. A filter which is slowed in this way is commonly said to have black in it.

The above explains the necessity for using a color filter, and the chapter on selective absorption will explain how the filters act.

The adjusting of the color filters to the sensitive plate is done by trial and error (see Chap. xxii.).

CHAPTER XVIII.

THE INFLUENCE OF THE ULTRA-VIOLET RAYS.

Besides regulating the action of the visible rays upon the plate, a filter is also necessary to prevent the action of the ultra-violet light. When making photographs of the spectrum it will be noticed (provided that in the spectroscope only colorless glass is used) that beyond the visible dark violet end of the spectrum there is a region of great activity due to the presence of ultra-violet rays. This will be well noticed if an electric arc be used as the source of light. In the actual photographing this ultra-violet light is present, and, as it is not visible, it should have no effect on the photographic plates. It will be necessary, therefore, when making the three-color negatives, to prevent its action.

If the prism and lenses in the spectroscope be constructed of materials very transparent to this light (use Iceland spar or quartz for the *complete* optical train), the effect of the ultra-violet will be shown at a considerable distance beyond the visible portion of the spectrum. The glass used for photographic lenses, also for color-filter cells, stops a considerable portion of this ultra-violet light, and the rest (near the visible spectrum) must be stopped by means of the color filters.

As glass lenses are used in photographing the colored object, only a small proportion of the ultra-violet light is transmitted, and this small amount can generally be stopped by the dyes used in the color filters. Picric acid and potassium chromate, or bichromate, are very effective filters for these rays.

It should be understood how the ultra-violet light acts in a detrimental manner. Suppose we attempt to photograph a colored picture on the three negatives, and let there be no provision made for the exclusion of the ultra-violet light, then the latter may be reflected indiscriminately from any of the pigments in the picture copied, and, if allowed to act, would give in the negative density which should not be there. If it be supposed that an equal amount of ultra-violet is reflected from each of the pigments an equal amount of density would be caused on this account; any action due to the colors of the pigments would be in excess of this. Again, if more ultra-violet is reflected from some pigments than from others, if the color sensitive plates and filters have been adjusted by the spectrum, there

will be an excess of action in those colors which reflect ultra-violet light, producing a false effect.

Without using the photographic test the existence of the ultra-violet light may be readily seen by allowing the spectrum to shine on a piece of black card moistened with acidulated sulphate of quinine. Or, without using the spectrum, the existence of ultra-violet light in arc light can be shown by letting the arc light fall on the black card, when the blue glow will be noticed. Fish glue or lubricating oil can also be employed to show this effect.

In making the color filter the residual ultra-violet or amount passed by glass must be cut off. This is, in general, readily effected by the dyes used in making the color screens.

CHAPTER XIX.

THE POSITION OF COLOR FILTERS.

So long as the light which is to form the image passes through the color filter before reaching the sensitive plate it is immaterial (so far as the color absorption is concerned) where the filter is placed. There are several possible positions, each of which will be discussed.

1st. Color filter on illuminant. The filter may be placed in front of the electric lamps or other artificial source of light. This method possesses one advantage, namely, that there can be no distortion of the image due to the surfaces of the glass not being plane and parallel.* The large size of the filters, and the great heat to which they are subjected, are disadvantages.

2d. Another position is in front of the lens. For this purpose only a small filter will be required, slightly larger than the *stop* used. Both in this position, and when close behind the lens, and also when at the diaphragm, the filter must possess parallel and plane sides, and, if dry, the *films* and *sealing* also should be optically homogeneous. A liquid filter can always be made homogeneous by stirring, but the cell or trough in which it is placed must be constructed of perfectly plane glasses, otherwise the image will be distorted or put out of focus. This is not of so much moment when occurring in a small degree when using a color filter for orthochromatic work, but when required for three-color work, where the three images are required of identical dimensions, it is of great importance. The position of filter in front of lens admits of ready changing. When placed in front of the lens a color filter receives more light than when behind, and especially is this so when a stop is used. It is generally advisable to avoid unnecessary exposure of the color filters to light.

3d. In the third position the screen is put between the combinations of the lens. In this position the filter can be smallest; it is not readily removable; and the lens may require modification to receive it.

4th. The fourth position, behind the lens, and close to the back combination, is a useful one. The three filters, especially if dry, can

* Though there may still, with some lenses, be a difference of foci of the different rays.

be mounted in a frame, and made to slide across the back of lens. Or the filter may be contained in a hinged wooden frame like a book, half of which is fixed to the camera and the other half holds the lens. They are thus always under cover and not exposed except when in use.

5th. The fifth position calls for remark. In this position, namely, close to the plate, the glass of the filters does not require to be so flat or parallel as in other positions, but it requires that the color absorptions should be uniform over the whole of the surface used, and the filter must be of the same size as the image.

This is the position of the filters used in the multiple back supplied for taking the negatives for making the transparencies used in the Kromskop. It avoids the necessity of using worked glass, and as the pictures are small the difficulty of getting perfect filters is not great. The thickness of the glass composing the color filter, also the thickness of water or alcohol contained, will affect the focus. The greater the thickness of dense medium the greater the lengthening of focus. Obviously, then, it would be preferable to use filters made of the thinnest glass and placed touching the plate. If the filter were on the surface of the plate or incorporated in the gelatine it would be better still.

CHAPTER XX.

SELECTION OF GLASS FOR FILTERS. OPTICAL REQUIREMENTS IN LENSES AND FILTERS.

In the 2d, 3d, and 4th positions for color filters, the supports and materials of which the filters are composed must have no distorting influence upon the rays passing through the lens. The defects likely to arise are alteration of size generally, lack of sharpness, and difference in size of *parts*. The first and second defects may be due to the thickness of the color filter not being allowed for in the focussing, which should be done either through the actual filter or a dummy of the same thickness, but without coloring matter. They may also arise from the glasses not having plane surfaces. The third defect is also due to lack of planeity.

Should the glasses be prismatic and not parallel the effect will be to displace the image very slightly. This would probably not affect the registering of the three images.

Great care must be taken to get the pieces of glass plane on both sides and parallel or approximately so.

The working of glass parallel and plane is difficult even to the experienced and capable optician, and such glass is, therefore, expensive, though various prices may be paid according to the accuracy of working of the surfaces. It is quite possible to select pieces of patent plate from a glass merchant's stock which are sufficiently plane for most purposes.* The cost of this is virtually nothing compared with the cost of worked glass, but it requires careful selection. It is hoped that the following account of how this can easily be done will be of service to those who wish to examine their optically worked glass or to choose pieces of patent plate, etc.

The Testing of Surfaces.

The method is an optical one, and has the advantage that the quality of the surfaces can be directly observed and estimated. The tests are of both planeity and parallelism.

The simplest test for planeity is to observe objects, particularly straight lines, after reflection by the surface, to discover if any dis-

* Some glass can be procured approaching optically worked glass in quality. It is thick and white, and can be obtained from Messrs. Hetley, glass merchants, Soho Square, and from other glass dealers.

tortion exists, or to reflect by the surface the sun's rays after passing through a lens, when the image should be free from distortion; another way is to look at the reflection of an object in the surface to be tested while the glass is moved to and fro. A convenient object is the glowing filament of an electric lamp, and the glass should be moved about on a flat surface. A test for parallelism is to examine the image of a *distant* small flame after reflection in both surfaces of the glass, when, if parallel, only one reflected image is seen. Another way is to look at an object through the glass, which is moved rapidly to and fro in a plane across the axis of vision, when any lack of parallelism in the glass causes the displacement of the object.* For more delicate tests apparatus is required, but substantially the same methods are adopted as given above.

The only apparatus required is a telescope of about two to three feet focal length, and from 2 in. to 3 in. aperture will be suitable. If provided with cross wires in the eye-piece better results are obtained. The telescope should be a good one, as on its definition is dependent the accuracy with which the estimations can be made.

First, the telescope should be turned toward some distant, distinct object, and carefully focussed; if provided with cross wires these should be in exact focus also. Next, the distant object is viewed in the telescope after reflection, at an angle of 45° (say) by the surface to be tested. Now, parallel rays from the distant object fall upon the surfaces and remain parallel after reflection if the surfaces are plane. If the surfaces are not *plane* the reflected beams will give images in the telescope which are not *sharp* or *distinct*. If the surfaces are not *parallel two images* will be seen. We may suppose that a transparent, colorless, and almost parallel piece of glass is being examined; to examine each surface separately the back surface should be coated with a black backing (as used for photographic plates).

It may happen that a surface will give a good image if only the focus of the telescope be altered; the surface in this case is of regular figure, and is acting like a lens. This can easily be detected by the cross wires of the telescope. If the telescope is not so fitted care must be taken that the focus plane of the eye is not altered.

Instead of viewing the reflected distant object a collimator to give parallel rays may be used. This is like the collimator of a spectroscope. A tube like the telescope has at one end a fine slit, and at the other end a lens at the distance of its equivalent focal length. This is accurately found in the following way. Carefully focus the telescope on the distant object out of doors, and then place a lamp flame outside the slit of the collimator, and, without disturbing the focus of the eye-piece of the telescope, alter the distance between the slit and lens until the image of the slit is seen perfectly

* If the glass is concave the object apparently moves in the same direction as the glass; if convex in the opposite direction.

sharp in the telescope. The collimator is now set for parallel rays. The surface to be examined is now placed so that the light issuing from the collimating lens falls upon it, and, after reflection, is viewed by the telescope.

The above tests are so simple in action that anyone can perform them. Thus, instead of a telescope, even a pair of field or opera glasses of large aperture can be used, using only one eye, or the camera lens may be employed for the purpose. The ground glass should be replaced by a piece of plain glass, or a microscopic disc balsamed to it, and a focussing magnifier used, adjusted to focus a diamond scratch on the microscopic disc.

A still more rigorous test is by the use of optical proof planes, but this is an unnecessary refinement.

Those who require further information should consult Glazebrook and Shaw's "Practical Physics" (Longmans, Green & Co.).

Forms of Cells.

The selected glass may be made into a cell or used for a dry filter, as desired. Color cells, more or less optically perfect, can be bought. They are of two kinds: one, optically worked, is capable of taking apart. It consists of two circular pieces of glass optically worked

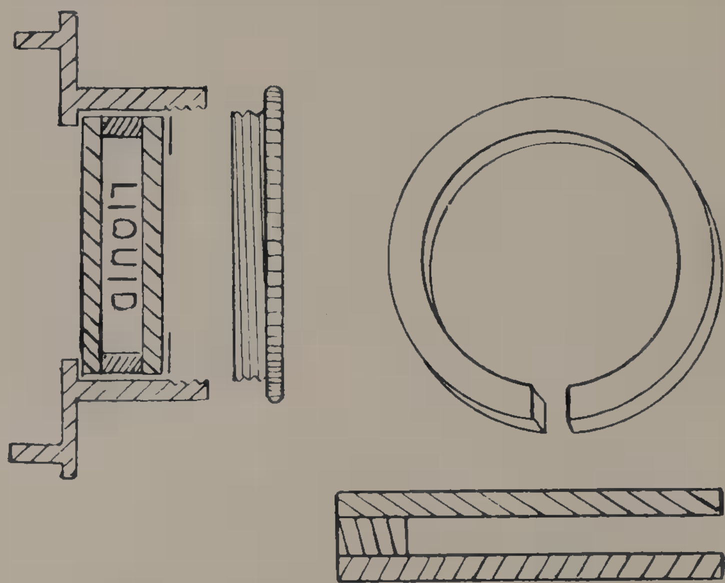

Fig. 48. Cells (2) for liquid filters.

plane and parallel. There is a separation piece consisting of an annular ring with a portion removed. This ring is also optically worked. The two sides of the ring are smeared with vaseline, and

the faces placed against it. The whole is placed in a thin brass frame like a lens hood. (See Fig. 48.)

The flange is intended to be pushed into the hood of lens, which forms a very simple and ready mode of attachment. The slit in the ring is for the purpose of filling or emptying the cell, there being a corresponding hole in the brass casing (a pipette is useful for this purpose).

Such cells are made with the accuracy of lenses, and, in consequence, are expensive. From the method of construction they can be readily taken apart, cleaned, and refilled with a dye solution when taking three-color negatives, consequently one only need be purchased. Messrs. Zeiss supply a cheap cell for holding colored solutions for microscopical purposes. The glass of these is selected for flatness, and is remarkably true, while the price is only 5/- for a size about four inches square. A section of this filter is shown in Fig. 48.

Difference in sizes of images due to lens.

Another cause of distortion is due to the lens. It sometimes happens, especially with the older lenses, that the three images are not exactly of the same size. It will readily be understood that with lenses uncorrected for chromatic aberration the three images may be of different sizes and formed at different distances from the lens. In the newer English and German lenses this defect is not noticeable. To secure three images of the same size by focussing *may* be possible, but the method is impracticable for business purposes.

The size and distortion of the images due to the color filters and lens may be tested by taking the three negatives of a monochrome subject or a subject containing fine lines, and from two making transparencies by contact; these should then be applied to the negatives, each to each, in close contact, and examined for coincidence of images all over. To test for equal size of image only, a transparency can be photographed *behind* which are three strips of colored glass similar to the color filters. In this way the three color images are made simultaneously and on the same plate.

Should the filters cause any alteration in the size or form of the images it will be impossible to register them, and, consequently, a poor result will be produced both in regard to color and to drawing; also the difficulties in registering images of different sizes increase very largely. Every endeavor should be made to get the images of identical size in all their parts.

Too often the printer attempts the impossible task of registering images which are not identical in size. The registering of images dissimilar in size is impossible; but when they are alike no difficulty is experienced.

A slight lack of register in the three images gives a faulty color

effect out of all proportion to the original error, and not only is the printer blamed for his inability to produce the sharpness of image and color effect, but he is wasting his time upon an impossible matter.

An excellent instance of the confused effect due to lack of register is shown in three-color projections with Ives' demonstration lantern. Here the three images can be moved apart and gradually superposed. If only *very* slightly out of register only a jumble of colors results.

CHAPTER XXI.

THE MANUFACTURE OF COLOR FILTERS.

Color filters are of two kinds, (1) wet and (2) dry. The wet filters are colored solutions used in a cell. Dry filters consist of one or two plates of glass on which is some medium, such as gelatine or collodion, holding in a dry state the coloring matter.

Wet and Dry Filters.

Wet filters are mostly employed in experimental work, on account of the facility offered of changing the dye or altering its strength. Also the same cell may be used in taking all three negatives. The readiness with which a filter can be made up is also a recommendation, all that is required being a cell of properly worked glass and a clear solution of dye.

The latter may be in various strengths, or may be a strong solution reduced with water or alcohol to suit requirements.

The disadvantages attaching to wet filters are their liability to be split; they are, therefore, not so portable; also the liability to evaporation; also, being in a wet state and exposed to the atmosphere, there is more liability to fading. Where they can be readily renewed, the wet filters have some advantages. They can be conveniently placed in position on the lens, either in front or behind.

In making a wet filter, the coloring matter, whether aniline dye or solution of metallic salt, should be made into solution in either water or alcohol, the former being best on account of cheapness and lesser evaporation. It should be noted that the color of the dye may change with the solvent; for instance, brilliant yellow—a most useful dye for orthochromatic or three-color filters—is more orange in an aqueous than in an alcoholic solution.

A measured quantity of dye may be dissolved in a measured quantity of solvent, or a saturated solution may be made which can be reduced in strength as desired. Some dyes leave a considerable amount of insoluble matter, which makes the statement of the strength of the solution indefinite, particularly as with some dyes the color changes rapidly with change of strength of solution. A convenient way of ensuring regularity is by direct comparison, in

similar color cells, of the standard solution* and the one under examination.

A convenient way of matching a standard is to take a saturated solution of dye and add it to solvent, drop by drop, until sufficiently strong; this is preferable to making it too strong and reducing afterwards. The cell should be carefully cleaned, and all fluff removed from the inside; if the cell is cemented temporarily with vaseline, alcohol may leave a scum over the face of the cell. A pipette is very convenient to fill cells with. As a matter of precaution against alteration, all color solutions should be kept in the dark when not in use. They should also be tested occasionally for fading, and any dyes decided upon for use in color filters should be tested by exposure to sunlight, covering up some portion to serve as a guide.

One advantage possessed by wet filters is homogeneity, the coloring matter being evenly distributed throughout the solution. This is not so readily attained in dry filters.

Dry filters are by no means so readily produced as wet.

They require optically worked glass or selected plate, according to the position of the filter, and, in general, two pieces for each filter.

If several dry filters, say of differing strengths of the same coloring matter, are to be used, it entails the possession of several pieces of glass, and, consequently, greater expense.

Gelatine or collodion is generally used for the medium.

Use of gelatine.

There are two methods of using gelatine: 1st, where the gelatine is applied to the glass and subsequently dyed in the colored solution, and, 2d, where the dye is added to the gelatine and applied to the glass. This latter method admits of little variation, and is only useful when the exact depth of dye has been previously determined. The method of procedure will depend on the number of filters required.

By the first method rough filters can be readily prepared by fixing lantern dry plates in hyposulphite of soda solution, clearing in ferricyanide and hypo. if necessary, and washing and immersing in dye solution. The depth of color can be regulated by the concentration of the dye and time of immersion.

A series of filters, made in different strengths of the same dye, may thus be readily prepared.

When a suitable strength of color is found by trial—spectroscopic or otherwise—a filter may be made on better glass by coating optically worked glass, previously levelled, with a carefully filtered

* For this purpose the Tintometer is exceedingly useful as giving means of comparing and stating in definite terms.

and clarified* solution of gelatine, and, when dry, immersing in the dye solution, and drying again. The gelatine coated plate should then be bound up with another plate to prevent change and injury, or two glasses, both coated, may be bound together. The film may be varnished with celluloid varnish or mastic in benzole, and balsamed to the cover glass. Heat should be avoided in balsaming, and therefore it is preferable to use dried balsam dissolved in benzole, as used by microscopists.

Four "dog" clips can be attached to the four sides of the filter to squeeze out the surplus balsam. Any balsam attaching itself to the face of the filter can be removed with alcohol or benzole, and the filter is then ready for final testing.

Use of collodion.

Collodion color filters are more quickly made than those with gelatine on account of the quicker drying of the collodion. They may be made by soaking collodionized glass in aqueous dye solution, or by adding dye, soluble in alcohol, to collodion, and coating glass plates with it. The plates should be previously coated with a substratum of albumen or gelatine. A strength of collodion of five grains of pyroxylin to the ounce of mixed solvents is suitable. The collodion should be in a very fluid condition, and care must be taken to avoid thickening of the edge of the film where the collodion is poured off. To counteract the thickening, two plates should be coated, and their positions reversed when bound together.

The collodionizing should be performed in a warm, dry atmosphere, and precautions taken to avoid dust. The plates should be varnished, and balsamed together.

Mr. Ives' recommendation.

Mr. Ives has recommended, for use with Lumière's panchromatic plates, a solution of brilliant yellow and fuchsin for the red record negative, and a piece of chromium green glass optically worked (this may be procured from Hetley's, Soho Square), and brilliant yellow dye for the green negative. For the blue record negative he recommends a blue-violet dye and a piece of chromium green glass of a lighter shade. The materials recommended give excellent results, and are simple, but as there may be difficulty in getting the green glass it is advisable to replace this by a dye.

Simple Formulae for Filters.

Only three dyestuffs are required—brilliant yellow, naphthol green, and methyl blue (these should be procured from Messrs. Hopkin and Williams, chemists, 16 Cross Street, Hatton Garden).

*Gelatine may be readily clarified by boiling a solution with a little egg albumen.

The filter for the red record negative is made by a strong solution of brilliant yellow, of a reddish orange color (a little fuchsin may be added with advantage). The green filter is made up of a strong solution of naphthol green and brilliant yellow until a yellowish green color is produced. The blue filter is composed of naphthol green and methyl blue. These filters confine the action in the negatives to the part desired and cut off the ultra-violet. The above three dyes make a good starting point for experiment. They can be adapted either for Cadett spectrum plates or for Lumière panchromatic plates.

For fuller information reference should be made to Mr. Ives' demonstration of color screen making in the Photographic Journal, Vol. xx., No. 11.

CHAPTER XXII.

SELECTING COLOR-SENSITIVE PLATES AND COLOR FILTERS, TO SECURE, WHEN PHOTOGRAPHING THE SPECTRUM, DENSITY PATCHES CORRESPONDING TO MAXWELL'S COLOR CURVES.

Preliminary Spectroscopic Test.

The first method requires a spectroscope fitted up with a convenient source of white light and a camera attachment. A spectrum of three inches long from red to the end of visible violet is convenient. Datum lines, either Fraunhofer lines or lines due to burning salts, should be used as guides to the position of the colors. When a brand of color-sensitive plates has been decided upon, successive exposures should be made upon the spectrum through the color filters until the appearance of the density patches on the negatives approaches the form of the curves in Maxwell's diagram. A previous visual examination of the color filter with a pocket spectroscope and a photospectroscopic test of the plates are very useful. Various dyes in various strengths must be tried with the particular brand of plates used.

The method is one of trial and error. The conditions of the experiment should be kept as even as possible, as the observed effect is altered by the amount of development and exposure.

The method must be regarded as only giving a preliminary trial of a qualitative nature, to be followed by the quantitative method, which is next explained.

Abney's Three-Color Sensitometer.

There are two other methods suggested and used for the adjustment of the color filters to the plates. The first is a method due to Sir W. Abney and described by him in Photography, Vol. x., No. 492. It is a development of the very ingenious piece of apparatus known as Abney's color sensitometer, referred to on pages 144 and 145. The results are given quantitatively as well as qualitatively and certain troublesome points in experimenting with the spectrum are avoided. For instance, the results are independent of the development. No camera is used and the operation is as simple as printing a transparency.

The principle of the working is as follows: Instead of using the

colors of the spectrum, which to many is unobtainable, to make experiments upon, colored glasses* which represent the principal divisions of color in the spectrum are used.

The problem is:

1st. To find out how much each of these test colors should affect the three negatives respectively (page 137).

2d. To choose suitable color filters and color-sensitive plates.

3d. To provide a ready instrumental means of determining when the desired result is obtained.

Pieces of colored glass, free from defects, and of about ½ inch square, are mounted on another strip of glass with lantern binding. This is the test object. The colors chosen should be representative of the principal colors of the spectrum, and the selection should have reference to the defects in the distribution of color sensitiveness of the plates used. Thus, a deep red and some shades of green are colors which might not be properly rendered by the plate.

Care must be taken that the glasses do not allow wide bands of spectrum colors to pass through.** This can be avoided by superimposing suitable glasses; thus an approximately pure green light may be obtained by a green glass combined with a yellow glass and a blue-green glass. Each of these glasses is used to stop certain colors of the spectrum. The green glass stops red and violet, the yellow stops blue, and the blue-green stops red and yellow. Thus red, yellow, blue, and violet are stopped, leaving only green. The green glass alone passes orange, yellow, green, and blue. (This combination is used in the Kromskop.)

The best colors to use for the test glasses are red, orange, yellow, yellow-green, green, green-blue, cobalt blue, pink, and white. The use of the latter is to ensure that the other colors are rendered quantitatively correctly with respect to white (page 106). A little wooden holder like a dark slide should be made to hold the glasses and the sensitive plate.

This part of the apparatus is now ready.

We have now a convenient artificial spectrum to experiment with, and the next thing is to find the value of each of these test colors in terms of their effect upon the sensation nerves, or, rather, their available substitutes represented by the reproduction colors. The three reproduction colors are red, green, and blue-violet in narrow bands of the spectrum. We want to find how much each of our test colors should affect the respective red, green, and blue record negatives, so that transparencies from these negatives may allow these amounts of reproduction color to come through and reproduce the colors of the test glasses. This is done by *matching* each test color in *hue and brightness and purity* by a similar color

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* See page 142 for the reason why *approximately* homogeneous beams may replace *pure* spectrum colors.

** They can be examined in strong light by a pocket spectroscope or by superposition.

made by mixtures of the three reproduction colors. Thus a table can be prepared giving the amounts of red, green, and blue in each test color. (Abney's article should be referred to for the method of doing this. See also Chapter xiii. for instrumental means.)

Now, knowing these values for each color, how are we to know when our filters pass the right kind of light to affect the plates in the proper degree? To measure the deposits would be irksome, and the results would depend on the possibility of the plate to render gradations correctly, and to some degree on the amount and quality of development. Sir W. Abney has applied the same ingenious device to this method as is used in his color sensitometer. Knowing the values of each color, rotating sectors or patches of density are interposed before each test glass to reduce these values to one value; for example, suppose the test glasses should affect the red record negatives in the relative degrees, white 100, red 20, yellow 60, green 5, then the patches of density necessary would have transparency values for white one-twentieth, for red one-fourth, for yellow one-twelfth, for green unity; that is, the white is to pass 100 x one-twentieth equals 5 units, the red is to pass 20 x one-fourth equals 5 units, the yellow is to pass 60 x one-twelfth equals 5 units, and the green 5 x 1 equals 5 units, or remains unaltered. These are the values of the stimulation of the red sensation nerve or the opacity of the deposits of the red record negative made by contact with the test glasses when a correct filter is used.

By the method of trial and error various filters are tried until a sufficiently close approximation to these even values of deposit is secured. Similar sets of values are found for the green and blue negatives and filters adjusted to give even densities.

The above method of securing the adjustment of plates and filters depends for its accuracy upon the accuracy of the measurements, the closeness with which the three reproduction glasses match the three spectrum colors in hue, and the number and purity of the color test glasses, and also on the degree of uniformity in density secured in the test negatives.

All the measurements and suiting of filters can be made by artificial light, and the filters when found are available to be used by any light. The method enables fresh filters to be easily prepared and checked without further apparatus or experiment.

The method appears complicated, but in reality is not so, and, when one has the necessary apparatus, offers great advantages over any other method of adjusting color screens. By whatever procedure one adjusts filters there is some difficulty and time must be expended.

There is always a great deal of unnecessary labor attendant on trial and error methods, and perfection cannot be attained until measurements take the place of rule of thumb procedure.

Another Method.

Another method consists of placing patches of the inks to be used in printing on cardboard and photographing them, adjusting the filters continually until the desired result is obtained. This method, if properly carried out, might serve as a good check on filters already established, but as a means of discovering suitable filters it is not sufficiently accurate. It is generally carried out in a very inaccurate manner, and for the following reason:

The idea that blues *always* photograph light and reds dark is still prevalent, though incorrect.

If plates were sensitive to color as color they would exert a selective action according to their color sensitiveness, but plates are sensitive to a large range of the spectrum and (speaking broadly) are quite indifferent to what colors are set before them. Thus, with a plate sensitive to all the colors of the spectrum, the exact hue of a color is immaterial to the plate; it photographs all colors according to their brightness.

Three patches of printing inks in full strength, pink, yellow, and blue, are laid down on white cardboard, and three negatives, through suitable filters, made. Each patch being in full strength (*i.e.,* solid) is as deep as a negative can put down or print. It therefore corresponds to a shadow in the negative, and when rephotographed for the test it should appear in the negative (which prints that color) as a "shadow," that is, as clear glass. Thus let the diagram represent the three patches, and the opacity or transparency of the three negatives in the places corresponding to the three patches. The white paper on which the patches are placed plays an important part in this test when properly performed. It must be remembered that white paper reflects all the rays reflected by the pigments (see also page 128).

Printing Negative	Pink	Yellow	Blue
Pink	Transparent	Opaque	Opaque
Yellow	Opaque	Transparent	Opaque
Blue	Opaque	Opaque	Transparent

Fig. 49. Adjusting Color Filters on Printing Inks.

Now, by reference to the discussion on the ray composition of the printing inks (pages 109 and 130) it will be recalled that a pink ink, for instance, is required to act in producing all the colors from blue to yellow, that is, it reflects about two-thirds of the spectrum.*

* This is at present a moot point until the color ray composition of the pigments is definitely determined.

Without other check experiments we are unable to know what rays have action in the negative. Further, some white light and ultraviolet are reflected, so that in the ray composition the whole spectrum is acting* (remember that the color filters are not yet fixed). Even without a color filter it is possible that *equal* density may result. The same is true for the other colors.

If the printing colors are correct both in hue and luminosity then correct negatives might be obtained, but if a printing color be a little too light or too dark (mixed with black or complementary colors) there is no criterion of its color action. The mutual absorptions of the inks must also be taken into account. Thus patches of red, green, and blue should also be made by printing and photographed (page 128).

To make this experiment successful it is necessary to be in possession of correct filters, which it is the object of the experiment to find.

The most that can be said of the method is that it affords a means of adjusting filters to *incorrect* pigments, though even in this case the method of three-color sensitometry, as above explained, is as applicable.

It cannot be too distinctly emphasized that in three-color photography (not so in interferential color photography) there are two factors—the hue of the reproduction color and the quantity of the color or its luminosity; one is as important as the other, and without due regard for both the results will be imperfect. (*Cf.*, a certain *quantity* of pink pigment mixed with a certain *quantity* of yellow pigment produces a red of a certain hue and luminosity. Variations of these *quantities* will produce variations both in *hue and luminosity.*)

* An extension of Abney's method of three-color sensitometry would be useful to fix the hues and relative luminosities of the printing inks (see pages 126 and 160).

CHAPTER XXIII.

THE RELATIVE EXPOSURES.

Having chosen color-sensitive plates and adjusted color filters to them, the next point requiring consideration is the relative exposure required by each negative.

These are found by the following artifice. Consider the method by which the picture in colors is to be shown, say in the Kromsk̄op (page 179). The three-color reproduction glasses are so related in luminosity that when illuminated by an evenly lit sky the resulting field in the instrument is white. Consequently absence of kromogram gives white, or equal transparencies give shades of white (greys); and, necessarily, equal densities in the negatives give shades of white. Therefore, white or shades of white must be represented in all three negatives by equal densities. To adjust the exposures, all that is necessary is to place the color filters in front of the plates and discover by trial what relative exposures have to be given to produce equal densities when exposed to white light. This may be done in a variety of ways. One is to place a piece of clean white (*i.e.*, colorless) blotting paper on a copying easel and photograph it, with color filters in position, on the color-sensitive plate, repeating the operations until a sufficiently near approximation to equality of density has been secured. It is presumed that the plates are the same and receiving the same amount of development during the tests (see Influence of Colored Lights, page 95).

Instead of a piece of white blotting paper a platinum print of a grey color can be used. This assists in guessing the relative exposures.

Another way is to dispense with the camera and let the white light fall directly upon the sensitive surface through the color filter. This method is quicker than by using the camera, and is in general too quick to allow of properly timing the exposures.

A convenient method is to take a piece of glass and cover it with black paper attached near the edges of the glass. Three little shutters, say 1 inch long and ½ inch wide, are then cut out of the centre of the black paper; the cuts are made on three sides only, leaving hinges. The glass with shutters and the sensitive plate are put into the dark slide together, and the shutters can be lifted up and turned back when it is desired to expose any section. The exposures

can now be made either in the camera or directly to the white light. The three images touch at their sides, and this enables any difference of density to be easily seen. Messrs Marion have quite recently put on the market a printing frame with little shutters to withdraw, which should be quite suitable for the purpose.

When a uniform light for making the exposures can be depended upon, greater accuracy can be attained in adjusting the relative exposures. Messrs. Hurter and Driffield's method of testing the speed of plates could then be employed for this purpose.

If a scale of opacities be made on the same plate by known amounts of light, the three patches may be referred to these and the exact relative exposures calculated.

A small error in relative exposure can be corrected during the subsequent operations, such as in the exposure in making the transparency. It will be useful to consider what is the effect of incorrect exposure.

Equal opacity in the three transparencies gives white or shades of white. Suppose that the red sensation negative is slightly under-exposed relatively to the other two, the negative will be thinner generally than the others. If the transparencies receive the same treatment the transparency from this thin negative will be relatively too dense. It will then stop too much of the red light, thereby causing the picture to become deficient in red and to show an excess of the two other mingled colors, green and violet. The picture will be too bluish in color.

A convention with regard to exposures.

On page 115 it is mentioned that there are several methods of drawing curves showing the relative proportions of the reproduction colors required to counterfeit the simple spectrum colors; one of the methods gave equal curve heights of the reproduction colors to equal white. This may be illustrated thus: white light, the brightness of which is unknown, passes through suitable red, green, and blue glasses, the transparencies of which are unknown, and produces on mixture white. Variations in the amounts of light passing through the glasses produce various colors. Now exactly similar transparencies, from exactly similar negatives, cut off equivalent amounts of the three lights, and give a monochrome picture. (By the way, it may be mentioned that this constitutes an excellent test for equality of exposure, etc., and for manipulative skill.) This seems a very reasonable way to establish the relative amounts of colored light, density, etc., and it is certainly the most convenient, as white is a more definite standard than any color, any little departure in hue is most readily noticed. There are other plans which are interesting if not useful. One is to use reproduction colors which are so regulated as to give equal brightness. The three colors, then, acting in full strength, will make a color instead

of white. It would not then be so easy a matter to find the relative exposures or to adjust the apparatus. To utilize this method the negatives and transparencies should be relatively altered according to the brightness of the colors used, and the respective quantities required to make white light.

The student may copy chromolithographs in his earlier attempts and find that the violet negatives are generally thin and lacking contrast. This does not happen so much in the case of outdoor objects, and it may give the impression that the exposure is incorrect. This is not so, however; it is due to the print photographed having a general yellow hue. This causes the violet record negative to look thin and under-exposed. The relative exposures having been determined these values should be adhered to in spite of the peculiar appearance of the negatives.

CHAPTER XXIV.

THE NECESSITY OF USING ONE KIND OF PLATE. INFLUENCE OF DEVELOPMENT ON THE THREE IMAGES. DARK ROOM LIGHTS.

Where the aim is to do exact work it is imperative that one kind of plate be used on which to make the three exposures, and again, not only the same kind of plate, but from the same batch, and they must be developed under identical conditions as regards strength and constitution of developer and length of time of development. The reasons for so doing are as follows: Suppose the subject to be a series of graduated tints in grey (such as a print on platinum paper), and let it be required to reproduce this by the three colors. Now, the subject photographed being colorless the three negatives taken through their appropriate color screens should be *identical* in their opacities, as has been before explained in the chapter on exposures. This relationship will be upset, however, unless each of the negatives receives the same amount of development. Let the diagram represent graphically by the equidistant lines a series of tints in the object photographed. (Fig. 50 (a).)

The effect of altering the amount of development which one of the plates receives will be to alter the contrasts, shown graphically by altering the spacing, thus: (b) under-developed, (c) correctly developed, (d) over-developed.

In these diagrams the middle tone in each is represented in the same place, for the sake of clearness.

Now, suppose one of the negatives receives too little development compared with the others, and also suppose, for the sake of simplicity, that the middle tints are alike, it will be obvious from inspection of the diagrams that the remaining tints are not equal, and that consequently there will be a color surplus, and the picture, instead of being colorless, will be colored in its gradations at both ends.

Different plates require different amounts of development to make identical images* (see page 143), and to avoid this difficulty the *same* plate should be used.

The easiest way to ensure equal development is to use the same

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* It should be noted that it is not always possible to make identical images on different plates on account of the difference of range of equiproportionate gradation (correct period).

plate, and to develop the plates together in the same dish, and in the same developer for the same time.

In the majority of cases it will be required to copy as literally as possible the object in colors placed before the camera. Apart from the difficulties introduced by color there are several points which need consideration. The first is the difficulty of reproducing exactly a monochrome object.

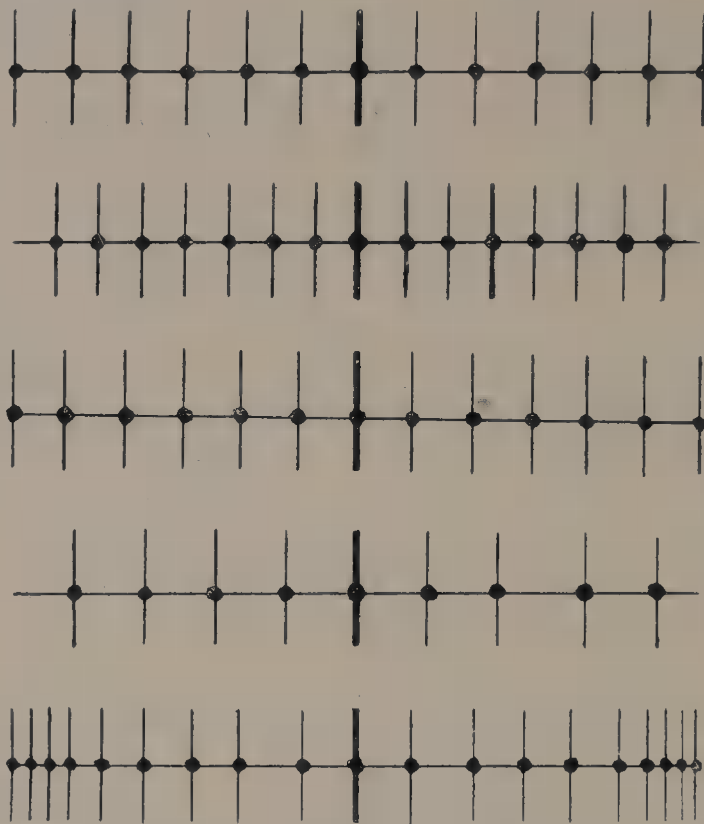

Fig. 50. Graphic representation of Influence of Development and Failure of Plate.
(a) The Tones photographed. (b) Under-development—lack of contrast. (c) Correct development—Tones correctly represented. (d) Over-development—excess of contrast. (e) Failure of Plate at both ends of Scale. Represented by a model made of elastic and beads.

The experimental work of Messrs. Hurter and Driffield has shown that dry plates possess four periods of *representation.* These are called the under-exposure, the correct, the over-exposure, and the reversal periods, respectively. Only in the correct period are the tones proportionately represented. The length of the period of correct representation varies with different plates, that is to say, different plates are capable of representing exactly various ranges of tone or contrast. In order, therefore, that the plates chosen may represent with accuracy the object photographed the latter should

possess a range of tone not greater than the plate can properly record. Care must therefore be taken, when possible, to reduce the contrast in the object to be photographed to the necessary limits by giving it a more even illumination.

Also, in order to secure the position of the majority of the tones of the object on the period of correct representation of the plate it will be necessary to give a correct exposure.

No definition of correct exposure has been given, but where literal reproduction is required it may be taken to be such an exposure that the tones of the object photographed fall within the limits of correct representation of the plate.

It may possibly happen that the two ends of the scale are not proportionately represented, in which case, as in a monochrome reproduction, there will be a slight error. The appearance would be like Fig. 47 and Fig. 50 (e).

This effect is to a great extent independent of the amount of development received by the plate. It is a defect inherent in the plate, and only very slightly influenced by change of developer, etc. Using the bead and rubber analogy it is as if the beads were more crowded together at the two ends.

Where the contrast in the object photographed is great, it becomes more necessary to use a plate capable of correct representation, or, at least, one in which the errors at the two ends of the scale are not excessive. Unfortunately it is not possible to test for this properly without using apparatus. There are several ways in which the test may be made. One consists in making a series of exposures on the plate, measuring the patches of deposit by an opacity meter, and plotting the results to show graphically the curve of opacities. This method is very thorough, but it requires apparatus; it is in fact the method of Sir W. Abney and Messrs. Hurter and Driffield.

It is important to remember that differences of tone can easily be rendered more visible by longer development, but this may cause such contrast that the plate is useless for printing. What is required is that the gradations should be visible throughout the exposures without undue development.

Those interested in the subject should read Messrs. Hurter and Driffield's first paper on "Photochemical Investigations." An excellent account of these researches is given in a small pamphlet entitled "Hurter and Driffield's Photochemical Investigations"; also in another called "The Action of Light on the Sensitive Film," by Dr. F. Hurter; both of which can be obtained gratis from Messrs. Marion & Co.

This cramping of tones might be noticeable in the case of one of the negatives being very thin all over, owing to lack of exposure (see remarks about yellow print, Chap. xxiii.). The majority of its tones might be formed in the under-exposure period.

An instance may be useful in this connection. Consider a very

light color which might be considered a shade removed from white. From the foregoing it will be understood that unless the plate is capable of giving correct (equiproportionate) gradation in all its range these lighter tones are very liable to be lost. Abney gives in Chap. x. of his "Color Measurement and Mixture" that the lightest tint of color visible is one seventy-fifth part in brightness of the white light composing it. Such an extremely light tint would therefore be lost in a color reproduction.

Influence of the developer on the three images.

Mr. Ives, in the instructions for using his cameras, recommends that metol without bromide should be used, the reason given being that the three images do not suffer the same treatment with some other developers. Thus, in 1893, at the Society of Arts, he said: "With certain developers—hydroquinone being one—the image of the blue-violet sensation commences to develop first, and goes on almost to completion long before the detail is all out in the image of the red sensation, even though the latter may appear relatively over-exposed after the development is fully carried out. Under such circumstances, the relation between the two images will vary with the time the plate is left in the developer, and it is difficult to insure accuracy. This difficulty was substantially overcome by using the eikonogen developer, and seems to have entirely disappeared with rodinal development."

In this connection it is interesting to note that Sir W. Abney, at the Camera Club Conference in 1897, said:

"Starting with the assumption that a red, a green, and a blue gave equal densities on a plate, and that, if each light were equally diminished, the densities remained equal if the exposure were more prolonged, he said he had already shown that time exposure and intensity of light, when a constant quantity, would not give the same result if the intensity was diminished, and also that the temperature of the sensitive surface altered the gradation of a plate and its comparative sensitiveness. He had now tested the relative sensitiveness to color, or rather the gradation obtained from color, and summarized the results which he obtained. With an ordinary plate, whatever ray of the spectrum was used, the gradation remained the same with a diminished proportion of light; but, if, say, a violet ray and a red ray were made to give the same density, the density would not remain the same if the intensity of the rays were diminished; the red would be much steeper in gradation, and all trace of any action in the red would disappear long before the action in the violet ceased to appear. A curious factor was that an isochromatized plate followed the law of an ordinary plate where the isochromatism had no effect, but that all the parts rendered more sensitive by the isochromatizing solution followed the steeper gradation; the plate thus contained, as it were, two sensitive salts—one the ordinary, or bromide, and the other the dye. It seemed that the plate was sensitive to rays in its bromide constituent, and in its coloring matter by those rays which could bleach or alter it in composition, the action of the silver salt in contact with the dye being a secondary action, the altered dye being the means of affecting a small change in the silver salt which enabled development to take place. Whether these considerations would enter into the question of color photography he did not know, but, if so, they

must also enter into ordinary photography where screens were used, in which case the gradation would be more harsh, for instance, where a deep orange screen was used than where it was omitted, or where a lighter one was used." Extracted from a report in the British Journal of Photography, May 7, 1897, No. 1931, Vol. 44.

Dark room lights. Filters.

When using plates which are sensitive from end to end of the spectrum, the observation of the plate during development becomes a matter of difficulty. Even when no light is required during development, as when the development is timed, this universal sensitiveness becomes a nuisance, as it allows of no light being used in the manufacture of the plates. To avoid this difficulty the Cadett Spectrum plates have a narrow gap of red insensitiveness near the end of the visible spectrum. This, though not appreciably affecting the image, allows of a faint red light being used during the operations of coating and examining the plates.

Glass filters for dark room lamps allowing only this narrow band of red to pass can be procured from the makers of the spectrum plates.

For those who wish to make their own " safe lights " the following selection of dyes advised by Sir W. Abney should be used, a gelatine film dyed with methyl violet, and another dyed with brilliant yellow, or, instead of the latter, bichromate of potash in solution. The methyl violet stops a broad band in the orange and green, and the yellow stops the blue and violet, leaving only a narrow band of red at the end of the spectrum. Mr. Sanger Shepherd recommends for these plates two combinations of dyes, one safer than the other. The more exclusive is made by dyeing gelatine films (dry plates fixed and washed), one in an aqueous solution of naphthol yellow, and another in an aqueous solution of aurantia. When dry coat one (on gelatine side) with collodion stained with brilliant green G, and the other with fuchsin in collodion. Varnish the two films and bind together. A screen passing more light, but not quite so safe, may be made by using naphthol yellow and aurantia, and substituting methyl violet 6 B for the brilliant green and fuchsin.

Backing the plates.

Backing the plates is of great importance in three-color work by whatever means the negatives are taken, whether for the Kromskop, Dr. Joly's process, or for screen and color negatives on dry plates. It is particularly in negatives of the red record that halation is likely to be found, and for this a greenish-blue dye in collodion is most useful.

DIVISION IV.

THE PRINT.

VARIOUS MEANS OF UTILIZING THE COLOR RECORD NEGATIVES TO PRODUCE THE FINAL RESULT IN COLORS.

There are two classes of methods for obtaining the final result in colors. They are:

A. Pure Photographic Methods.

By Optical Synthesis.	I.	Transparencies for the Kromskop.
	II.	Transparencies for the Triple Optical Lantern.
	III.	Transparencies for Dr. Joly's method.
	IV.	Professor Wood's Diffraction Process.
By Absorption.	V.	Stained Positive Process. (Triple Superposed Positives.)

B. Photo-mechanical Methods.

By Absorption.	I.	Photo-engraved Typographic blocks.
	II.	Other Photo-mechanical Printing Processes.

CHAPTER XXV.

THE KROMSKOP AND PROJECTION LANTERN.

The best way of showing color photographs produced by the three-color method is by means of an instrument called a Kromskop (formerly called Photochromoscope). By this method of color

reproduction the results are produced under conditions to give the best effect. The correct reproduction colors can be easily secured in the color filter glasses (hue), and can be made very exclusive, *i.e.*, approaching to narrow bands in the spectrum, thereby heightening the color effect (purity). The photographs being transparencies there are no surface reflections, an absence of grain, and a long and correct range of gradation, which, with the advantage of stereoscopic relief and freedom from distracting surroundings, produce a more perfect illusion than any other method.

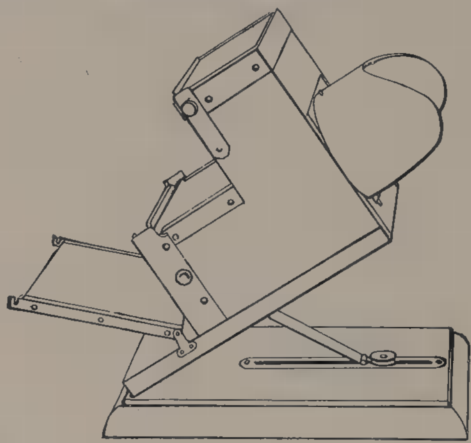

Fig. 51. The Kromskop (Stereoscopic).

This instrument was devised by Mr. F. E. Ives, to whom is due the credit of bringing the process to its present state of perfection.

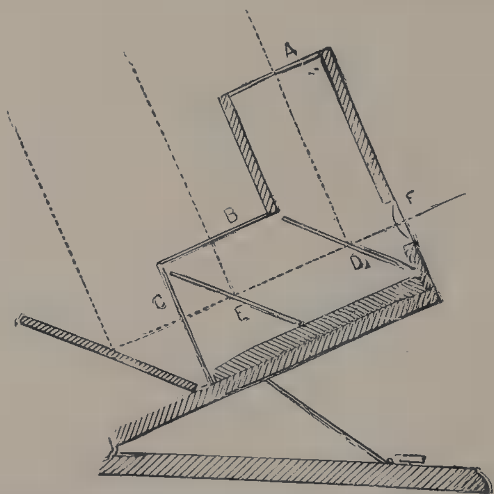

Fig. 52. The Kromskop, Skeleton view.

It combines means for holding the transparent positives and their respective color filters, and reflectors by whose aid the three colored pictures are optically superposed. Fig. 51 shows an external view of the instrument, and Fig. 52 gives a skeleton sectional view.

The three transparent positives, or Kromograms, made from the record negatives, are placed in position at A, B, and C (Fig. 52). D and E are reflectors made of transparent colored glass. When the Kromograms are placed in their proper positions and the adjustments of the instruments are made, the three images are exactly superposed when viewed through the eyehole and magnifying lens F. Thus the image at A is viewed after reflection by the transparent mirror D. The image at B is viewed after reflection by the transparent mirror E, the light passing, without appreciable deviation, through the mirror D. The image at C is viewed directly through the two mirrors E and D. The eye at the lens F views all three images exactly superposed in position and of the same size. When it is intended to use daylight as the means of illumination an even expanse of sky, or preferably white cloud, is used, and the dotted lines represent the course of the rays. The illumination of C is secured by a mirror, as shown in the diagram. The distances of the images from the lens F are the same in all three cases. It will be obvious that the image C being viewed directly and the images A and B after one reflection, these latter Kromograms must be inverted; that is, turned top to bottom. These three images should appear, when viewed without their respective color glasses, to give one image only if the instrument is in correct adjustment and the positives are of the same size and without distortion and at the same distance.

Underneath the positives at A and B are the colored glasses which are used to filter the light coming through the positives. Thus at A is a red glass, at B is a violet glass, and at C a white glass. The mirrors at E and D having appreciable thickness there would be seen two reflections, one from each surface; this is avoided by making each mirror of colored glass, which absorbs light of the color which it is intended to reflect from the first surface. Thus the reflection from the back surface of mirror D of the colored image at A is avoided. D is a greenish-blue glass—the complementary color to the red at A—thus any red is prevented passing through D to the second surface. The mirror E is of green glass; the second reflection at E of the light from B is also stopped, the green glass absorbing violet. The violet light from B passes through D and has the small quantity of red removed from it. The light passing through the positive at C traverses the green glass at E and the greenish-blue glass at D, emerging at the eye-piece as a pure green color. The color of the glass at E is known as chromium green, at D as cyan blue, at B as cobalt blue, while A is a dyed film of a deep red. The reflector opposite C is yellow, and so the light from the positive at C passes through yellow, green, and greenish-blue. The three reproduction colors, by the absorptions in the glasses, are reduced to an equivalence with three broad bands in the spectrum. When the instrument is placed opposite to an even white sky the field of view in the eye-piece should be white (page 166); this is regu-

lated by a careful choice of the glasses and by the amount of dye which is added to the film at A. The movable mirror at C and the tilt of the instrument give control over the illumination. A slight general color is not a great drawback to the use of the instrument,

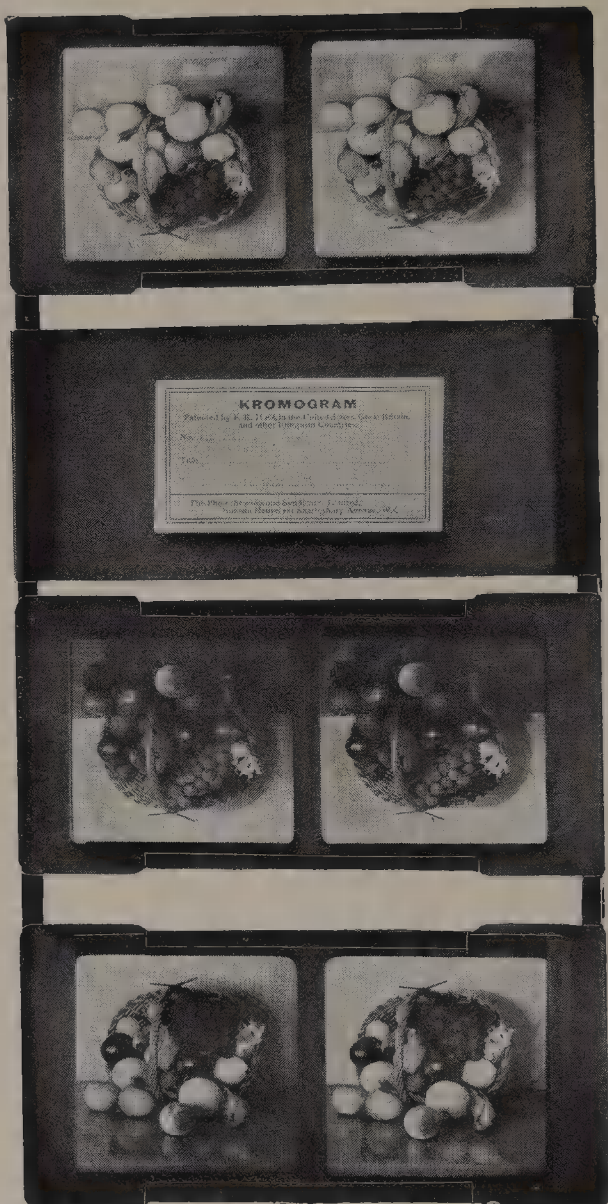

Fig. 53. Stereoscopic Kromograms.

but every care must be taken to secure even illumination over the whole of the field, such irregularities as white clouds on a blue sky, or blind cords, sash bars, foliage, and other obstructions must be guarded against. When such obstructions are unavoidable the ground glass

diffuser supplied with the instrument should be used. At night time the lamp supplied with the instrument should be used. This burns ordinary coal gas in a Welsbach incandescent burner, and this yellow light is made of a more neutral color by the aid of a light blue glass. This is shown in Fig. 54.

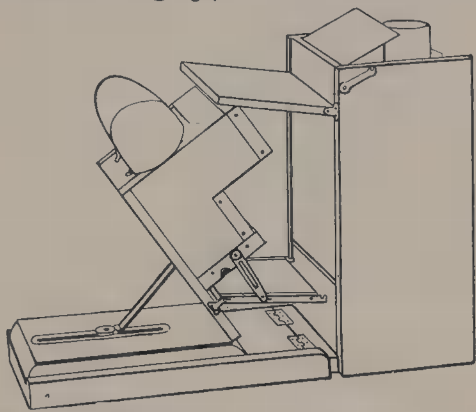

Fig. 54. Lantern for Artificial Illumination.

The Principles of Working of the Kromskop.

The mingled light through the three glasses produces white* (page 166), and if any two of the glasses are covered up the red, violet, and green are severally produced. If only one at a time is covered, two of the colored lights are mingled at the eye-piece, giving, as detailed in an earlier chapter, yellow, blue, and pink. This experiment should be actually performed by any possessor of the instrument who is interested in its performance. Hence are produced white by full intensity of all three colored lights, black by the total suppression of color, also red, yellow, green, blue, violet, and pink. By placing pieces of developed dry plates over the colored glasses the shades intermediate between any two of these main divisions of color can be produced. Thus will be demonstrated the power of the instrument to produce any color and any shade of color desired. It will be readily seen that the positives or kromograms by the varying transparencies of the respective parts of their images can, by transmitting suitable quantities of the pure reproduction colors, counterfeit the infinite variety of color and light and shade of the original object.

Two forms of Instrument.

The instrument is made in two forms, binocular and monocular. In the latter only one set of images is used, but in the former a stereoscopic pair is placed on the instrument, which is duplicated to receive them. (Fig. 53.)

* Examine the white so made with a spectroscope; it is resolved into broad bands of color.

In this instrument both eyes are used and the two colored images blend into one, giving stereoscopic relief, increasing the impression of realism already given by the colors.

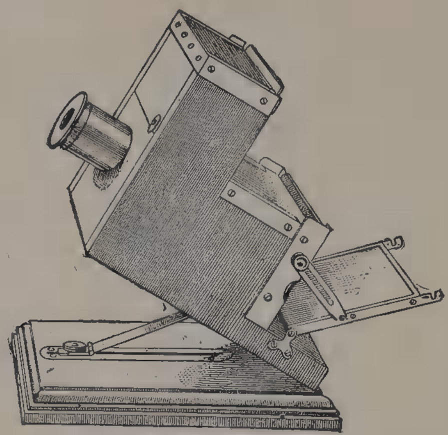

Fig. 55. Monocular Kromskop.

For further details respecting the care and adjustments and method of working the instruments, and for other information respecting them, reference should be made to a small manual edited

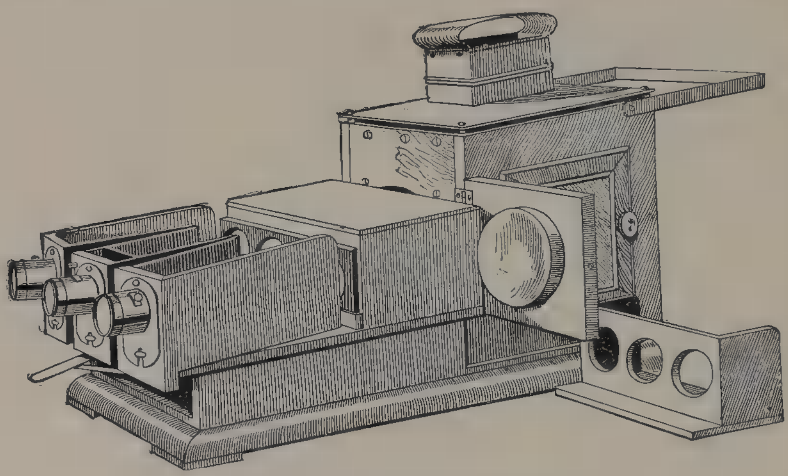

Fig. 56. The Lantern Kromskop.

by Mr. Ives, called "Kromskop Color Photography" (the Photochromoscope Syndicate, Ltd., 28, The Pavement, Clapham Common, S.W.).

Lantern for triple color projection.

Besides the instruments described above, Mr. Ives has designed a lantern Kromskop, by which demonstrations of the principles and the projection of color photographs on the screen can be readily

shown to a large audience of people. This is shown in Figs. 56 and 57. It consists of an arrangement for splitting white light (lime-light or arc light) proceeding from one source into three beams, which can be accurately adjusted in intensity by means of a special device. These three beams then pass through their respective color

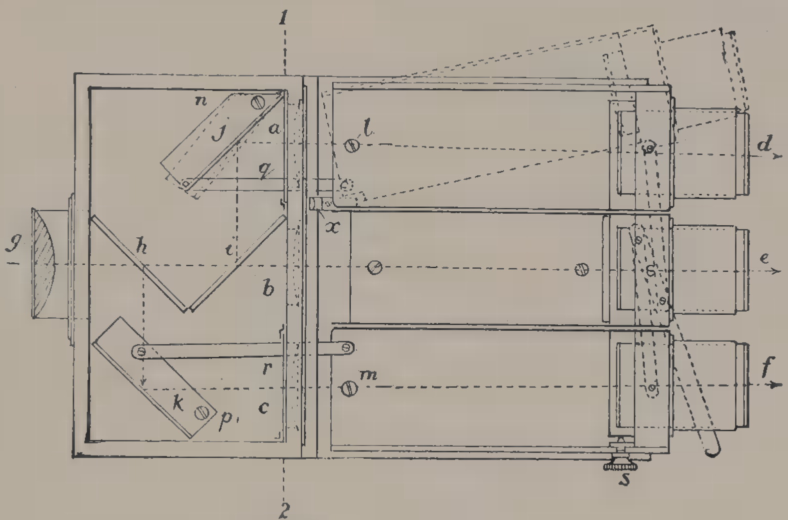

Fig. 57. Fittings of Lantern Kromskop.

filters and transparent positives, and are focussed by three equal objectives on to a lantern screen, where they are exactly superposed. By this instrument the color filters or the Kromograms may be readily shown separately or in pairs and the principles of the process demonstrated.

CHAPTER XXVI.

APPARATUS FOR MAKING THE COLOR RECORD NEGATIVES FOR THE KROMSKOP AND PROJECTION LANTERN.

In order that the color record negatives may be made as simply and accurately as possible it is essential to make the three images upon a single sensitive plate, by simultaneous exposure, from one point of view; also, the images must be of the same size and without distortion. In the manual above referred to will be found a description of a camera constructed by Mr. Ives to make satisfactory negatives. A view of the instrument is shown in Fig. 58. In this

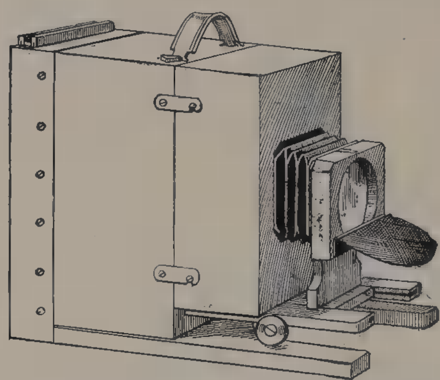

Fig. 58. Camera for taking the three images simultaneously on the same plate, by the same lens.

instrument only one lens is used, and the beam of light which it transmits is divided into three sections which pass through their appropriate color filters and are received on one plate after having their paths rendered equal in length by reflections. (Fig. 59.)

The differences in exposure required by the three negatives are regulated by diaphragms.

Stereoscopic pairs of images can be as readily taken by this camera, if it is constructed to take a wider plate, by attaching a pair of mirrors in front (Brown's stereoscopic transmitter) to give the two images. This also transposes the images so that the plates do not require cutting apart.

Such a camera is necessarily costly, and so Mr. Ives has devised an attachment for any camera, by which the color record negatives

can be readily made, but by *successive* exposures on the one plate. It is a simple instrument, and will make negatives for the lantern

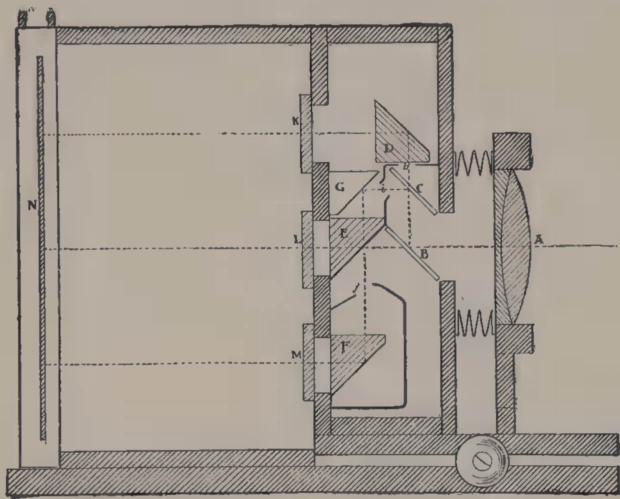

Fig. 59. Internal arrangements of Camera.

projection Kromskop or for the monocular or binocular Kromskop. (Multiple back, Fig. 60.)

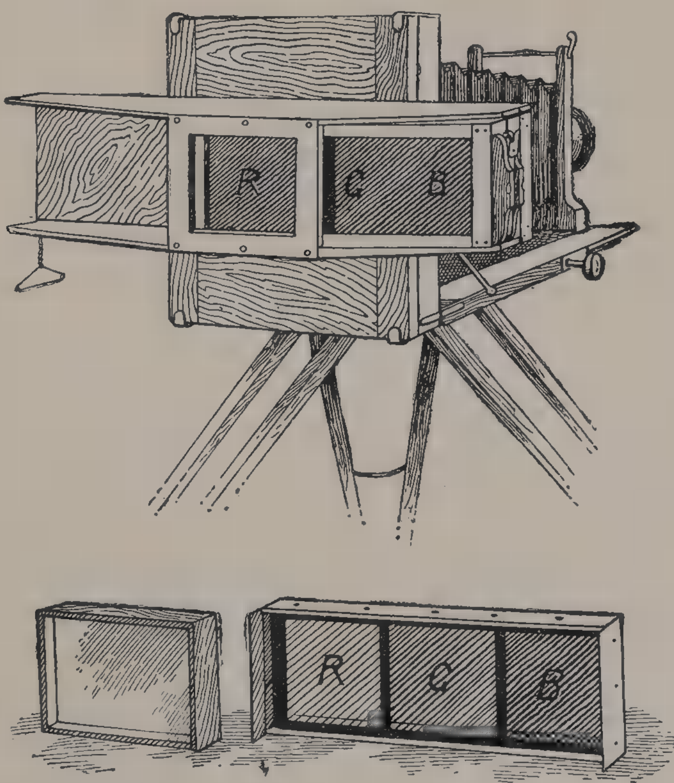

Fig. 60. Multiple Back for separate exposures on the same plate.

As the exposures are given successively, it is necessary that the object should not move, nor should the light change during the exposures, nor must the correct relation of the exposures be departed from. The figure shows the arrangement, called a multiple back, attached to an ordinary stand camera. It consists of a frame attached to a board, which is intended to take the place of the reversing back of a camera. This frame holds the color filters (which are permanent and dry, and consist of patent plate glasses, coated with aniline dyes, cemented together), and also the double dark slide. These are shown in Fig. 60. There is also a focussing screen in a wooden frame to take the place of the dark slide and color filters. The dark slide fits on to the frame holding the three color filters, and the two are pushed across the opening opposite the lens before each exposure is made. There is an ingenious con-

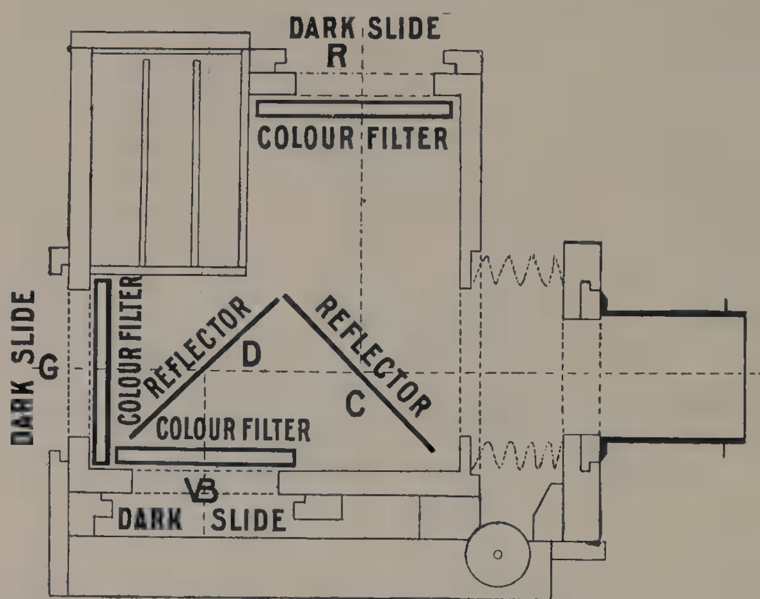

Fig. 61. Camera for taking three negatives simultaneously on three separate plates.

trivance added to ensure the accurate spacing of the three images, which is necessary when they are required for lantern projection. After focussing, the ground glass is removed and the color filter frame is inserted, and the dark slide is placed in position on the color filters between the brass lugs, and the whole arrangement is pushed to the extreme right. The relative exposures being known, the first or red exposure is given by cap or shutter, then the dark slide and color filter frame is pushed to the left until the middle position is reached (indicated automatically by a catch). The next exposure, for green, having been made, the two slides are pushed to the extreme left, and the blue or last exposure given.

There is another form of camera for taking the three images simultaneously on three separate plates. The construction can be

seen from the sketch, Fig. 61. R G V B represent the dark slides containing the sensitive plates, and underneath each are the color filters, red, green, and blue respectively. At C and D are two transparent mirrors; C is coated with blue dye on the under surface and D is of glass coated with yellow dye. The path of the rays is the same length in all three cases. The difficulty in arranging the mirrors D and C and the lack of control in exposures prevent the extended use of this form of camera. (See remarks on control in Dr. Joly's process below, page 187). Mr. Walter White has patented a camera constructed on these lines. By adding reflectors outside, his camera can be converted into a viewing instrument (see the *British Journal of Photography,* Vol. xlvi., No. 2050, 1899).

The development of Kromskop negatives—Transparencies.

Metol without bromide is the developer recommended for the development of these negatives, for the reason already given, that it acts equally on all three of the colored images. The formula is given in the handbook to the Kromskop, and is as follows:

Water	80 ozs.
Metol	1 oz.
Sulphite of Soda..........................	5 ozs.
Anhydrous Carbonate of Soda................	2½ ozs.

Dissolve in the order named.

It must be distinctly understood that the exposures must be correct and that the development must be conducted for such a time as would give a soft negative (*i.e.,* with little contrast). Negatives of great contrast (*i.e.,* hard) are useless for making the transparencies. The operations are similar to ordinary development, except that the plates being sensitive to red, etc., only a sparing use must be made of the dark room light. The first stage of the development should be conducted in darkness, and the negative not looked at until development is nearly or quite finished. Transparencies are made by contact on Cadett's or other makers' photomechanical plates, gas or lamp light being used. The correct exposure must be given, and here again care must be taken not to overdevelop, and a developer which gives a neutral-tinted deposit chosen, such as metol.

CHAPTER XXVII.

DR. JOLY'S PROCESS OF THREE-COLOR PHOTOGRAPHY.

This process is a modification of the process of Mr. Ives. Its object is the avoidance of taking *three separate* negatives respectively, red, green, and blue-violet. A glass plate, ruled with lines of transparent colored inks, is used in front of the photographic plate and in contact with it. These colored lines correspond to the color filters used in taking the color record negatives by Ives's process. After exposure and development, which is simultaneous for the three colors, the negative bears a series of lines of deposit corresponding to the amount of light which has filtered through the respective lines of the "taking" screen. To observe the result in colors a transparency is made from the lined negative in the ordinary way, and it is then placed in contact with another ruled plate called a "viewing" screen. This latter has upon it lines ruled in transparent colored pigments of the same number and width as in the "taking" screen. The lines of the "viewing" screen are made to exactly register with the lines of the transparent positive, and the colored result is viewed directly. Both screens bear about 250 lines to the inch, and at the normal distance of vision these are not very objectionably visible. At the present time experiments are being made with the idea of increasing the number of lines and so rendering them less visible.

It should be understood that the two screens are similar respectively to the taking screens and viewing screens of Mr. Ives. That is to say, the taking screen passes all those rays which affect the sensation nerves, whereas the viewing screens should only pass rays corresponding to narrow bands of the spectrum. In order to eliminate the ultra-violet and to secure more equal action of the rays a color filter is used on the lens.

The process is one of great simplicity, and can be worked without any modification of the camera, except the insertion of the taking screen in front of the plate in the dark slide, and a slight adjustment for focus. The colored transparency requires no apparatus to view it, except perhaps a piece of ground glass or sheet of white paper. As the transparencies are made on ordinary lantern plates, the glass of which is not always sufficiently flat, when the colored result is looked at sideways the colors change. This is due to lack of contact, and is the result of the lines of the transparency not

being seen under the proper lines of the viewing screen. The corresponding lines in the viewing screen and the positive must be exactly registered over one another in order that the colors may appear properly.

The operations are very simple, indeed, in fact involving nothing more than ordinary photographic operations. The taking screen supplied is placed in the ordinary book form of dark slide with the sensitive plate upon it, the slight difference of focus occasioned by the removal of the sensitive surface from the lens being allowed for in focussing by the screw or by using the ground glass reversed. A trial exposure is made to white paper illuminated by a white sky to see whether the three pigments in which the taking screen is ruled are in the correct depths to give equal density in the lines over the whole of the negative.

It will be understood that separate exposures through the colored lines are impossible in this process, so that alterations have to be made by an auxiliary filter used on the lens. This serves four purposes: it corrects any lack of uniformity in color of the lines of different taking screens, it stops the ultra-violet and reduces the blue and violet, and it permits of the use of different kinds of color sensitive plates, and serves to correct variations in distribution of color sensitiveness which would necessitate differences of exposure and cause slight differences in hue. To correct the color effect and to stop the ultra-violet a filter of gelatine-coated glass stained with picric acid is used, and if the green lines show want of exposure the filter is tinted green by soaking in a solution of ethyl green.

When white paper, photographed, gives equal density, then the photographs can be taken. A correct exposure is essential and development is conducted in the ordinary way. Ordinary lantern plates are required for the positive, the exposure being given to the direct rays from a lamp, to avoid any light entering under the wrong lines. The developed positive should be grey in color and free from stain. When dry the viewing screen is placed upon the positive and the lines exactly registered. Not only must the lines of the positive be opposite to the proper colored lines of the viewing screen, but any angling of the lines must be avoided, otherwise patterns in color are produced.

CHAPTER XXVIII.

TRIPLE SUPERPOSED POSITIVES.

We now come to the mode of producing the colored result by the superposition of three transparent pigmented images. This process has lately come into vogue, and pictures produced in this way are now commercial articles. The idea is by no means new, neither is the actual production of pictures by this means.

For reasons already given, the results produced by the methods of optical superposition are the best, particularly those produced in the Kromskop where colored lights corresponding to narrow bands in the spectrum are employed.

Of the methods employing pigments, the one which produces the best results is that of superposed dyed films. This has advantages over the analogous process of photomechanical printing in color in that truer gradations are possible and aniline dyes instead of colored inks can be used.

Aniline dyes are obtainable in great purity of color, and there is a large number of dyes available. A large amount of control can be exercised in using the dyes.

There are two distinct processes which demand attention. The first is printing on to gelatine films which are afterwards dyed, and the second the production of the dyed gelatine films by the Woodbury type process.

Of the first process there are several variations which are due to the various means by which the gelatine films are supported, composed, printed, developed, dyed, and mounted. For supports, either temporary or permanent, celluloid, mica, or thin microscopical glass (which can be procured in large pieces) is used.

It will be useful to consider what is required in a three-color positive. There appears to be no one process which embodies all the necessary points. It is necessary that the triple positive should be mounted on glass or between two glasses; a material such as celluloid is liable to damage, especially when used in the optical lantern where it is subjected to heat.

The three images should be made in thin films, without relief, and the supports should also be thin so that separation of the images is avoided. The use of supports of mica, celluloid, or microscopic glass is to be avoided when it separates the images. The use of material for support which is liable to cockle or to stretch is also to

be avoided. This effect of separation and relief can be partially avoided by optically cementing the three images together by balsam.

The sensitive material should be capable of giving an image in good contrast and of even gradation such as in the ordinary carbon process. It is found that the inclusion of the pigmentary colors in the sensitive gelatine films causes differences of gradation of the three images. It is, therefore, left out, and to prevent the high relief which would occur without it an insoluble material such as silver bromide is used, which is removed by fixing after development.

Unless such a film is exposed through the support, the half-tones are imperfect and tend to leave the support; this necessitates, when exposure through the back is resorted to, that the support should be transparent and very thin; or the sensitive material, after exposure, may be transferred to a final support and developed.

By the inclusion of the silver bromide (or other substance) in the film it may be developed without transfer. The resulting gradations are not so perfect as those produced by the other method.

The printing may be done, as circumstances permit, directly on to the film as in gum-bichromate, or as when intended for transfer, or it may be done through the support, which must then be transparent, and also thin to prevent loss of sharpness.

The method of development is generally to remove the unaltered gelatine by hot water. In Dr. Selle's process, cold water is used to removed the bichromate only, the altered and unaltered gelatine being left in the image.

The dyeing may be done in two ways, viz., in one by the varying thicknesses of the gelatine, and in the other by the difference in physical condition of the gelatine caused by the tanning action of light on the bichromated gelatine taking up varying amounts of dye. In both methods the dyeing is under control.

The mounting together and registering is effected in various ways. In one three films on celluloid or thin microscopic glass are placed together in balsam between glasses, in another the three films are made on collodionized glasses, and after finishing are stripped from their glasses and mounted together by balsam or other substance. In the process of Messrs. Lumière the first image is printed on a glass, developed and dyed, coated with impermeable varnish and again coated with sensitive material and printed under the second negative, developed and dyed, and the operations repeated for the third negative.

A practical process.

The simplest and best method for small sizes appears to be the one introduced by Du Hauron and afterwards employed by Mr. Ives in 1890. In this process flexible celluloid coated with silver bromide in gelatine, as used for rollable film, is sensitized in potassium bichro-

mate solution and dried; the three prints can be printed at one operation and developed in hot water, fixed and dyed after cutting apart. Mr. Ives recommends for the blue dye thio blue A, or soluble Prussian blue slightly acidified with sulphuric acid; for the pink fuchsin or aniline-magenta, or a mixture of eosin and rhodamine pink; for the yellow brilliant yellow or aniline yellow.

Mr. Sanger Shepherd is introducing commercially a systematized process for producing triple transparencies in colors in this way.

An excellent account of the various methods of production of three-color transparencies is given by A. Freiherr von Hübl (the author of the book "Die Dreifarben Photographie") in the British Journal of Photography, Vol. xlvi., Nos. 2043, 2047, 2051, June, July, and August, 1899. The following table giving particulars of several methods of making the color transparencies is based on the above-mentioned articles.

Support.		Composition of sensitive film.	Manner in which prihted	How devel-oped.	How dyed.	How mounted.	Similar to process.	Color secured by.	Name of inventor.
Temporary.	Final.								
	Mica	Gel. Bi. and pigment	back	hot	with Gelatine	3 films	Carbon	thickness of Gelatine	Du Hauron.
	Celluloid	Gel. Bi. Ag. Br.	back	hot	immer-sion	3 films	Carbon	thickness of Gelatine alterable	Mr. Ives.
Collodion Glass	Collodion and Gelatine Skins	Gel. Bi.	front	cold	immer-sion	3 flexible films	Novel	differen-tial action of exposed and un-exposed Gelatine	Dr. Selle.
	1 Collodionized Glass	Gum Bi. Ag. Br.	front	hot	with Gelatine or after by immer-sion	3 thin films coated on one glass	Gum Bi.	thickness of Gelatine	Lumière.

The Woodburytype process appears to be the most suitable for the production of dyed gelatine transparencies in quantity. It should be possible to regulate the amount of color and gelatine and so secure even results. Each separate print would require to be on a transparent backing like collodion, and the whole would be bound together with or without glass, some medium being used to ensure optical contact.

Mr. J. Wallace Bennetto is the author of another variation of the method of taking the color record negatives and of making superposed transparent prints.

He uses a simplified camera in which two images are produced. One image falls directly on one sensitized plate and another image falls, after reflection by a transparent mirror, on two sensitized plates placed film to film, which may have a thin color filter placed between them. For the positives three pigmented gelatine films sensitized by bichromate of potash are exposed under the negatives and developed separately as carbon prints on thin flexible transparent sheets of celluloid or such like. They are next treated with adhesive material and superposed in exact register. (An account of this process, with an illustration of camera, is given in the Photogram, Vol vi., No. 67, July, 1899.)

CHAPTER XXIX.

THE DIFFRACTION PROCESS OF COLOR PHOTOGRAPHY.

A variation of Mr. Ives's process of three-color photography has been made by Professor R. W. Wood, of the University of Wisconsin, U. S. A.

The method consists in taking the color record negatives as usual and from them making transparent prints in which the colors are produced by means of diffraction phenomena.

An account of Professor Wood's experiments is given by himself in *Nature* and is here reproduced by permission of the proprietors of that journal. An account is also given in the British Journal of Photography, No. 2044, Vol. 46, July 7, 1899. Professor Wood has been kind enough to send some working details of the process, which are also given.

The Diffraction Process of Color Photography.

"The production of color by photography has been accomplished in two radically different ways up to the present time. In one, the so-called Lippmann process, the waves of light form directly in the photographic film laminæ of varying thickness, depending on the wave-length or color of the light. These thin laminæ show interference colors in reflected light in the same way that the soap bubble does, and these colors approximate closely to the tints of the original.

"The technical difficulties involved in this process are so great that really very few satisfactory pictures have ever been made by it. The other, or three-color process, has been developed along several distinct lines, the most satisfactory results having been produced by Ives with his stereoscopic Kromskop, in which the reproduction is so perfect that, in the case of still-life subjects, it would be almost impossible to distinguish between the picture and the original seen through a slightly concave lens. The theory of the three-color method is so well known that it will be unnecessary to devote any space to it, except to remind the reader of the two chief ways in which the synthesis of the finished picture is effected from the three negatives. We have first the triple lantern and the Kromskop, in which the synthesis is optical, there being a direct addition of light to light in the compound colors, yellow being produced, for example,

by the addition of red and green. The second method is illustrated by the modern trichromic printing in pigments. Here we do not have an addition of light to light, and consequently cannot produce yellow from red and green, having to produce the green by a mixture of yellow and blue. Still a third method, that of Joly, accomplishes an optical synthesis on the retina of the eye, the picture being a linear mosaic in red, green, and blue, the individual lines being too fine to be distinguished as such.

"The diffraction process, which I have briefly described in the April number of the *Philosophical Magazine*, is really a variation of the three-color process, though it possesses some advantages which the other methods do not have, such as the complete elimination of colored screens and pigments from the finished picture, and the possibility of printing one picture from another. The idea of using a diffraction grating occurred to me while endeavoring to think of some way of impressing a surface with a structure capable of sending light of a certain color to the eye, and then superposing on this a second structure capable of sending light of another color, without in any way interfering with the light furnished by the first structure. This cannot, of course, be done with inks, since, if we print green ink over red, the result will not be a mixture of red light and green light, but almost perfect absence of any light whatever; in other words, instead of getting yellow we get black. Let us consider first how a picture in color might be produced by diffraction. Place a diffraction grating (which is merely a glass plate with fine lines ruled on its surface) before a lens, and allow the light of a lamp to fall upon it. There will be formed on a sheet of paper placed in the focal plane of the lens an image of the lamp flame, and spectra, or rainbow-colored bands, on each side of it. Now make a small hole in the sheet of paper in the red part of one of these spectra. This hole is receiving red light from the whole surface of the grating; consequently, if we get behind the paper and look through the hole, we shall see the grating illuminated in pure red light over its whole extent. This is indicated in Fig. 1, where we have the red end of the spectrum falling on the hole, the paths of the red rays from

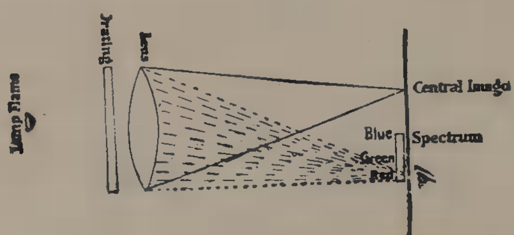

Fig. 1.

the grating to the eye being indicated by dotted lines. Now, the position of the spectra with reference to the central image of the flame depends on the number of lines to the inch with which the grating is ruled. The finer the ruling the further removed from the

central image are the colored bands. Suppose now we remove the grating in Fig. 1, and substitute for it one with closer ruling. The spectrum will be a little lower down in the diagram, and instead of the red falling on the hole there will be green, consequently, if we now look through the hole, we shall see this grating illuminated in green light. A still finer ruling will give us a grating which will appear blue. Now, suppose that the two first gratings be put in front of the lens together, overlapping as shown in Fig. 2. This

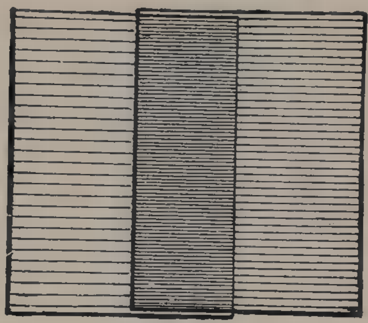

Fig. 2.

combination will form two overlapping spectra, the red of the one falling in the same place as the green of the other, namely, on the eye-hole. The upper strip, where we have the close ruling, sends green light to the eye and appears green; the under strip, with the coarser ruling, sends red light to the eye and appears red, while the middle portion, where we have both rulings, sends both red and green light to the eye, and, in consequence, appears yellow, since the simultaneous action of red and green light on any portion of the retina causes the sensation of yellow. In other words we have, in superposed diffraction gratings, a structure capable of sending several colors at once to the eye.

" If we add the third grating, we shall see the portion where all three overlap illuminated in white produced by the mixture of red, green, and blue light.

" Three gratings with 2000 lines, 2400 lines, and 2750 lines to the inch will send red, green, and blue light in the same direction, or, in other words, to the same spot on the screen behind the lens.

" Suppose, now, we have a glass plate with a design of a tulip, with its blossom ruled with 2000 lines to the inch, its leaves ruled with 2400, and the pot in which it is growing ruled with 2750 lines, and place this plate before the lens. On looking through the hole, we shall see a red tulip with green leaves growing in a blue pot.

" Thus we see how it is possible to produce a colored picture by means of diffraction lines, which are in themselves colorless. Those portions of the plate where there are no lines send no light to the eye, and appear black.

" We have now to consider how this principle can be applied to

photography. That photographs which show color on this principle can be made depends on the fact that a diffraction grating can be copied by contact printing in sunlight on glass coated with a thin

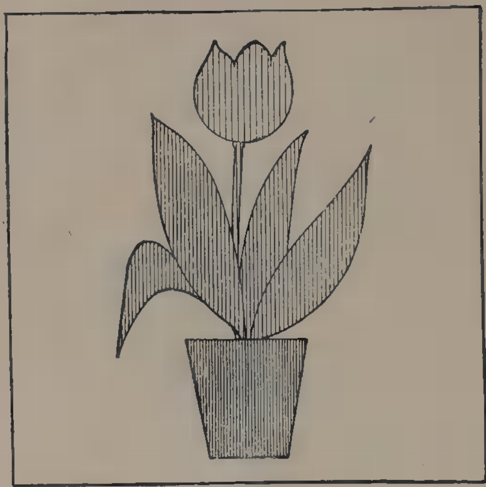

Fig. 3.

film of bichromated gelatine. The general method which I have found best is as follows: Three gratings ruled on glass with the requisite spacing were first prepared.*

"To produce a picture in color, three negatives were taken through red, green, and blue color filters in the usual manner. From these three ordinary lantern-slide positives were made. A sheet of thin plate glass was coated with chrome gelatine, dried, and cut up into pieces of suitable size; one of these was placed with the sensitive film in contact with the ruled surface of the 2000-line grating, and the whole covered with the positive representing the action of the red light in the picture. An exposure of thirty seconds to sunlight impressed the lines of the grating on the film in those places which lay under the transparent parts of the positive. The second grating and the positive representing the green were now substituted for the others and a second exposure was made. The yellows in the picture being transparent in both positives, both sets of lines were printed superposed in these parts of the picture, while the green parts received the impression of 2400 lines to the inch only.

"The same was done for the blue, and the plate then washed for a few seconds in warm water. On drying, it appeared as a colored photograph when placed in front of the lens and viewed through the hole in the screen. Proper registration during the triple printing is secured by making reference marks on the plates. A picture of this sort once produced can be reproduced indefinitely by making contact prints, since the arrangement of the lines will be

* These gratings were ruled for us on the dividing engine at Cornell University, through the courtesy of Professor E. L. Nichols.

the same in all of the copies as in the original. The finished picture is perfectly transparent, and is merely a diffraction grating on gelatine with variable spacing. In some parts of the picture there will be a double grating, and in other parts (the whites) there will be a triple set of lines. Having had some difficulty in getting three sets of lines on a single film in such a way as to produce a good white, I have adopted the method of making the red and green gratings on one plate and the blue on another, and then mounting the two with the films in contact. It is very little trouble to multiply the pictures once the original red-green grating picture is made.

"The pictures are viewed with a very simple piece of apparatus, shown in Fig. 4, consisting of a lens cut square like a reading glass,

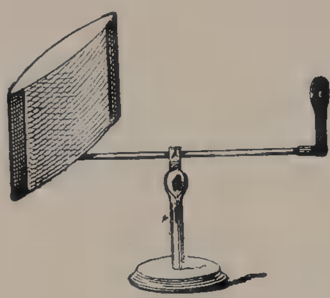

Fig. 4.

mounted on a light frame provided with a black screen perforated with an eyehole, through which the pictures are viewed. The colors are extremely brilliant, and there is a peculiar fascination in the pictures, since, if the viewing apparatus be slowly turned so that its direction with reference to the light varies, the colors change in a most delightful manner, giving us, for example, green roses with red leaves, or blue roses with purple leaves, a feature which should appeal to the impressionists. The reason of this kaleidoscopic effect is evident, for by turning the viewing apparatus we bring the eye into different parts of the overlapping spectra.

"It is possible to project the pictures by employing a very intense light and placing a projecting lens in place of the eye behind the perforation in the screen. Of course, a very large percentage of the light is lost, consequently great amplification cannot well be obtained. I have found that sunlight gives the best results, and have thrown up a three-inch picture on a four-foot sheet, so that it could be seen by a fair-sized audience.

"By employing a lens of suitable focus it is possible to make the viewing apparatus binocular, for similar sets of superposed spectra are formed on each side of the central image by the gratings, so that we may have two eyeholes if the distance between the spectra corresponds to the interocular distance.

"It is interesting to consider that it is theoretically possible to produce one of these diffraction pictures directly in the camera on a single plate. If a photographic plate of fine grain were to be exposed in succession in the camera under red, green, and blue screens, on the surfaces of which diffraction gratings had been ruled or photographed, the plate on development should appear as a colored positive when seen in the viewing apparatus. I have done this for a single color, but the commercial plates are too coarse-grained to take the impression of more than a single set of lines. With specially made plates I hope to obtain better results."

The following is a verbatim account of Professor Wood's method of making the diffraction pictures, which he has been good enough to send for insertion here:

"The gratings that I have used were originally ruled on glass, with 2000, 2400, and 2750 lines to the inch respectively. Photographic copies of these were used for the experimental work, in order not to expose the originals to risk of accidental fracture.

"The glass on which the diffraction pictures are to be made must have a flat surface, as ordinary window glass cannot be brought into close enough contact with the gratings to secure uniformly sharp impressions of the lines.

"A sheet of thin German plate, with its surface carefully cleaned, is flowed with a warm solution of gelatine and bichromate of potash made of

5 grains photographic gelatine,
125 c.cms. water,
2 to 3 c.cms. sat. sol. bichrom. potash.
(Filter warm.)

It is allowed to drain for about ten seconds and then placed on a *level* table in a dark and *dust-free* room. In about two hours it will be dry and can be cut into suitable sizes. It is best to begin by making simple copies of the gratings. An exposure of from 10 to 25 seconds in sunlight, the sensitive surface being placed in contact with the lined surface, is sufficient; the plate is then washed in warm water (35° C.) and stood on edge to dry. The copy, when placed in front of the lens of the viewing apparatus and viewed as described, should show a *brilliant* uniform color. Variations in the brilliancy indicate that the thickness of the film was not perfectly uniform, and this is the greatest difficulty that one has to contend with.

"When a fairly good single grating can be made, the composite grating or diffraction picture can be attempted. A piece of the sensitized glass is placed with its film in contact with the film of either one of the three positives made from the negatives taken through the red, green, and blue color screens. The two plates are held in front of a lamp, and two or three minute ink dots are made on the glass surface of the sensitized plate, coinciding with conspicuous *points* of

the picture, which show in *all* three of the positives. The corner of a white label on a bottle is a good example of such a point. Corresponding ink dots should now be made on the film side of the sensitized plate, and the other dots rubbed off. These dots serve as registration marks in the triple printing process.

" Now place the grating with the coarsest spacing, which is to furnish the red light, over the sensitized plate, and over this place the positive representing the action of the red light. The lines of the grating should be vertical and the ink dots on the sensitive film should be brought carefully into their proper position. As the ink dots are still separated from the positive by a space equal to the thickness of the grating plate, it is important to avoid errors of parallax by holding the plates perpendicular to the line of sight.

" Expose the plates to sunlight for about 30 seconds, holding them firmly in the fingers, and taking care that they are perpendicular to the sun's rays. It is best to do the printing in a partially darkened room with a narrow beam of sunlight, as diffused skylight is very detrimental. Now remove the grating and positive and substitute for them the ones representing green light and repeat the process, securing registration in the same meanner as before. Wash the plate in warm water, dry, and examine with the viewing apparatus. The shades of red, yellow, and green should appear in the picture. If proper registration has not been secured, there will be an overlapping at the edges of the colored impressions, and a second attempt should be made. If one color predominates over the other, making the yellows either too red or too green, the relative times of exposure should be changed. After a satisfactory red-green picture has been made, the third grating can be impressed on a second plate, under the positive representing the blue, taking care to put the film side of the positive out, in order that the two grating pictures can be mounted film to film without having left and right reversed. In printing the blue picture no registration marks are necessary, for after it is dry it can be brought into proper register with the red-yellow picture by holding the two in front of the viewing apparatus. It is possible to get all three sets of lines on a single plate, but I prefer to make the pictures as described, the chances of success being greater, and as a cover is required any way, it is very little more trouble to print the blue impression on it. If a number of pictures are required it is only necessary to strike off copies from the red-yellow combination and corresponding blue impressions, making the blue grating pictures with the film of the positive next the grating, since now left and right are reversed. In this way one can make the pictures about as rapidly as one can make lantern slides.

" R. W. Wood."

CHAPTER XXX.

THREE-COLOR TYPOGRAPHIC PRINTING.

The most important development of the three-color process, from a commercial standpoint, is the application of photomechanical methods to the production of prints in color.

Typographic, lithographic, photogravure, collotype, and Woodburytype methods have been employed successfully so far as quality of result is concerned, but all have been put aside in favor of the typographic method (examples of "screen" prints transferred to stone have given great promise and under certain circumstances might compete favorably with typographic work).

The typographic process is the one which shows the greatest promise of giving rapidity of reproduction and evenness of result.

The union of the color record making and the printing block making involves little that is new.

Color Filters.

The first consideration is the choice of color sensitive plates and color filters and printing inks.

The success of the final picture depends on three points, which are the hue, the luminosity, and the purity of its several parts (disregarding accuracy of rendering of form, which is a matter depending on the lens and glass of filters, etc.). A little reflection will show that the most important of these points is the hue or color The eye is very sensitive to changes of color, whereas a variation of luminosity or purity may not be noticed.

If, therefore, it is not possible to secure accuracy in hue and luminosity and purity, it is better to sacrifice the two latter to the former. Now, the effect of using improper pigments is that the hues resulting from their admixtures, though correct, are degraded in purity. If the correct pigments cannot be secured, the nearest approach to them must be used and allowance made in the "taking" color filters to ensure that the hues are correctly rendered.

This is effected in the simplest way by checking the filters, after a previous selection by spectroscopic means by photographing patches of the inks spread on paper, altering the color filters until the necessary result is produced in the negatives. This is, that each pigment should produce density in two negatives and trans-

parency in the third (see page 164). As has before been pointed out, lack of knowledge about the pigments prevents exact statements being made.

The filters may be used in either the wet or dry state. The relative exposures must be determined, and, as before mentioned, one kind of plate should preferably be used, or, when different kinds of plate are used to secure the records, the relative times of development should be ascertained from a scale of tones in grey, such as a strip of a (grey) platinotype print, which should be included in the object photographed and which should be rendered the same in all three negatives.

The Positives.

When the color record negatives are secured positives must be made, which may be either transparent or opaque. For the former, prints on paper must be made, and care must be taken that the prints are identical in size, which is ensured by cutting the sensitive paper the same way out of the sheet. When made upon silver papers, albumen, or gelatine, care must be taken in the toning that all three prints are treated alike, so that the color may not be altered. In fact, in all the operations the three prints must undergo identical treatment. To avoid toning a development paper is useful, Nikko paper being very useful for this purpose, as it gives a good surface and a black image. To avoid loss of tones at either end of the scale the negatives must be suitably developed, *i.e.*, the contrast in the negatives must be within the range of the printing paper.

The three prints are mounted wet on cardboard or glass. Instead of prints, transparencies can be made on dry plates and for some purposes are preferable. There is no risk of variable stretching, neither is there any color due to variation in toning. The use of non-staining developers, such as metol, gives a uniformity to all transparencies, which is a great assistance in estimating exposures. Care must be taken in making transparencies for this purpose that regular density is produced in different sets of negatives. It is very easy to be deceived by variations of density in a transparency (not so in a print, because the limit of blackness is soon reached). These variations of density not only affect the time of exposure in making the final screen negative, but affect the contrast of the transparency, and unless care is taken the contrast (or "hardness") may be so great that no satisfactory screen negative can be secured.

There is a certain amount of contrast of original which gives the best results in the screen negative, and under the usual conditions of working this is the contrast found in a "bright" print. This amount of contrast, then, is what should be aimed at in producing the transparency.

Copying the Transparency.

When copying the transparency to make the screen negative

there are three methods available. The first is the ordinary one of daylight enlarging, which is done by placing the transparency at a window and illuminating it by a diffused sky-light; or artificial light may be used, which is thrown on to a diffusing surface, and the transparency illuminated by this. The third method is to use artificial light and a condenser. *Unless, however, a diffusing medium is placed between the source of light and the transparency, a screen negative cannot, in general, be made correctly* by this method. Such a diffuser as a piece of ground glass is suitable. The light reaching the lens from the transparency will now act in a manner similar to when an opaque print is photographed, and is amenable to the ordinary rules for the use of stops and distance of ruled screen in screen negative making.

Angles of Ruled Screens.

The first departure from the ordinary procedure takes place here. It is found when two or more screen pictures are superposed that the lines of dots of ink produce regular patterns. This can be readily seen by moving two screen negatives* over one another, when according to the angles between the two sets of lines so are the patterns altered in appearance. These patterns are particularly noticeable when the two sets of lines are nearly coincident, when large patterns are produced which are very obvious and objectionable. When the greatest differences of angle between the two sets of lines are produced the pattern becomes least noticeable, it becomes smaller and more even. The most commonly used angles for the three sets of screen lines is where the lines make equal angles with one another. Thus, if each screen be set at 30° or 60° to the other, then each line will make an angle of 30° with its neighbor. Mr. Ives has stated that the best arrangement of screen lines is where crossing takes place at 22½°. (See The Photogram, Vol. vi., No. 68.)

Methods of Turning the Screens.

Means must be provided for turning the screen plate relatively to the object photographed, and this is done in a variety of ways. The simplest method is to mount the positives made from the color record negatives at the chosen angles. Thus, mount one print with its base horizontal, another print with the base at 30° to this, and the third print with its base at 60° to the first. These copies are then fastened on the copy-board and the three screen negatives made by successive exposures, sliding the copy-board across the axis of the lens. The screen plate and the sensitive plate must, of course, be large enough to take the diagonal of the copy.

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* Failing a screen negative two pieces of fine wire gauze can be rotated over one another.

Another method is to turn round the cross-line screen in the dark slide for each exposure. Here, also, the screen must be larger than the copy, but the sensitive plate need be no larger than the image required.

Another method is to use screens ruled at different angles. By this method a saving is effected in the size of the screen, but two screens are required.

The third screen can be dispensed with by simply reversing (turning front to back) one of the screens. Thus let one screen be ruled at 45° to the sides, and another at 15° and 75° to the sides, by reversing this latter another set of lines at 30° to it is produced.

The use of stops and the correct distance of the screen is found as in the usual practice. Mr. Ives recommends that a cross-line screen should be used and rectangular (slit) apertures in the lens. This gives to the dots an elliptical shape, which varies with the brightness of the parts of the picture. Thus in the high-lights of the negative the very fine dots are circular, becoming egg-shaped in the middle tones, and spreading out and merging in the shadows. Care must be taken that the relative exposures and contrasts are not altered in making the reproduced negatives.

The screen negatives may be on wet or dry plates, according to the fancy of the operator, and the exposure, development and fixing and intensification are performed in the usual way.

The blocks should be made on copper, and the etching of the three blocks carried through with as much uniformity as possible.

The fine-etching should be entrusted only to capable fine-etchers.

The printing of the blocks requires the greatest care, and should only be entrusted to those who have experience of the work. Besides the other qualities which constitute good printing the register must be carefully kept. This, as before explained, will depend almost entirely upon the exact coincidence in the sizes of the three-color images.

The inks must be chosen of the correct colors and must be so related that equal amounts of each printed give a neutral black. Sufficient time must be given between each printing to allow of the ink drying completely.

Color Record and Screen Negatives taken simultaneously.

One important departure from the ordinary method of working consists in taking the color record and screen negative together upon one plate. The method given above involves in all fifteen operations; they are, taking three-color record negatives, making three positives, three screen negatives and three blocks and three printings. By taking the color record and screen negatives simultaneously on one plate a great saving is effected.

The number of operations is reduced from fifteen to nine. By the use of rapid commercial color sensitive plates this is made pos-

sible, and where the subject allows of the necessary exposure being given the method is very successful. By this simplification of the process not only is economy effected, but errors, which creep in with the larger number of operations, are avoided. The class of screen negative produced on rapid dry plates differs entirely in appearance from those produced by wet collodion; they are, however, useable, and with care in the block-making excellent blocks can be made. The novel appearance of the silver dots in the negatives need be no deterrent to the use of the plates, though some experience is required. A closer screen distance or a smaller stop is in general required on account of the greater spreading action of light in the film.

The stops to be used may be the ordinary form in common use, square or round or both, as the operator is accustomed to use. A stop of rectangular form gives the best appearance.

The following formula for fish glue to be used on copper has been found serviceable. It is given by Mr. Ives.

Le Page Fish Glue (clarified for process work)	5	ozs.
Potassium Bichromate	88	grs.
Chromic Acid	40	grs.
Strong Ammonia Solution	1¾	drs.
Water	12	ozs.

Dissolve the potassium bichromate in 10 ozs. of the water and add the glue and well mix. Dissolve the chromic acid in 2 ozs. of water and add drop by drop, stirring continuously; then add the ammonia.

The remaining operations of block-making and printing are as in ordinary work.

APPENDIX I.

THE COLOR SENSATIONS IN TERMS OF LUMINOSITY.

By Sir W. de W. Abney, K.C.B., D.C.L., F.R.S.

In this paper, read before the Royal Society on June 15, 1899, and published in December, the author details the method he employed to determine the fundamental color sensations (based on the Young theory of color vision). The positions where these latter are located in the spectrum were determined, and the luminosities of the color components in white light, made by mixtures of the three chosen colors, were measured.

It was found that there is only one sensation excited at the red end of the spectrum, from the extreme limit to near C (Fraunhofer line), and that no mixture of colors will match it.

The violet, from the extreme limit to near G (Fraunhofer line), is also homogeneous, but is due to two sensations, the red and the blue, in constant proportions. The latter is never stimulated alone, as it is always mixed with some red or green. The position was found in the spectrum where the blue sensation was accompanied by red and green in the correct proportions to form white. This is at $\lambda 4580$, or close to the blue lithium line.

A provisional violet sensation, having a known and invariable composition, may, for convenience, be substituted for the red and blue sensations. (Pending the publication of this paper, the provisional violet sensation curve has been employed in the book. This of course, is permissible, provided that the red reproduction color is altered in amount, and that a suitable violet reproduction color is chosen.)

The position was found where the fundamental green sensation was most exclusively excited, namely, where the red and blue sensations are present in correct relative proportions to give white. This is at $\lambda 5120$.

From the measurements made curves were drawn, both for the prismatic and normal spectra. The curves are of three kinds, first, the *percentages* of color sensations, measured in terms of luminosity, in the spectrum colors; second, the actual sensation luminosities of the spectrum colors; and third, the sensation curves modified so that equal heights of ordinates form white. The areas of the sensation curves are also given.

The majority of the experiments were made in the light from the crater of the positive pole of the electric arc light (direct current), and were viewed with the centre of the retina.

The curves for sunlight are also given.

APPENDIX II.

"SCREENS FOR THREE-COLOR WORK."

By Sir W. de W. Abney, K.C.B., D.C.L., F.R.S.

In the Photographic Journal for January, 1900, Vol. xxiv., No. 5, will be found a report of a lecture by Sir W. Abney on a modified sensitometer for use in the preparation of color filters for orthochromatic and three-color work.

The preparation and principles of working of the sensitometer have been explained in Chaps. xvi. and xxii.

The present modification of the apparatus consists in replacing the colored test glasses by colored pigments, which are spread upon cardboard discs, capable of rotation, in concentric circles.

By suitable photometric methods, the value of each of the test pigments is ascertained, in luminosity if for orthochromatic work, and in terms of the three reproduction colors if for three-color work.

The amounts of colored pigment are next modified in accordance with these values, not by the use of rotating sectors or patches of density, etc., but by covering up portions of the colored rings by black pigment.

This having been done negatives of the rotating disc, or discs, are taken through color filters which are continually modified until all the circles on a disc are rendered in the negative by equal opacity.

A HANDBOOK OF PHOTOGRAPHY IN COLORS.

SECTION III.—BY EDGAR SENIOR.

Lippmann's Process of Interference Heliochromy.

LIPPMANN'S PROCESS OF INTERFERENCE HELIOCHROMY.

By Edgar Senior.

The great question of color photography in which a sensitive surface could be exposed in the camera in the ordinary manner, and the impression thus obtained be made to show the coloring in all its brilliancy of the objects photographed, is one which has received the attention of scientists for years past.

Edmond Becquerel, in 1840, was probably the nearest to reach the desired goal, as he actually obtained colored images directly in the camera. The colors, however, were not perfect, and, owing to the nature of the substance on which they were formed, could not be fixed, therefore could only be examined in a subdued or non-actinic light.

In the early part of the year 1891 Professor Gabriel Lippmann, a French physicist, announced that he had been able to produce direct in the camera photographs showing the spectrum in the true colors, and that the results were absolutely permanent. Startling as this statement appeared at the time the experiments have since been confirmed by others, and the writer has obtained by the method heliochromes in which the colors are remarkable for their brilliancy and clearness.

Lippmann appears to have worked out this process from a purely theoretical standpoint based upon the well-known phenomenon of interference of light, examples of which we have in mother of pearl, opal, and upon which the beautiful colors of a soap bubble depend and the colors of all thin films are due; and it is interesting as being an example of one of those instances in which theoretical reasoning based upon well-known scientific facts has led to the working out of a successful process.

Before proceeding to the practical part of our subject it will be necessary to explain to some extent interference of light and to show how it has been applied in the production of the results.

The generally accepted theory of light is that it, like sound, is the result of wave motion, and the medium for its transmission has been given the name of ether.

Now, these ethereal waves are not all alike, but vary in their lengths and amplitudes: Let A B, Fig. 1, represent the direction

of a ray of light, the ether particles vibrating to and fro at right angles to the direction of propagation, giving rise to the wave motion as shown. A C would be a wave length, D E the amplitude of

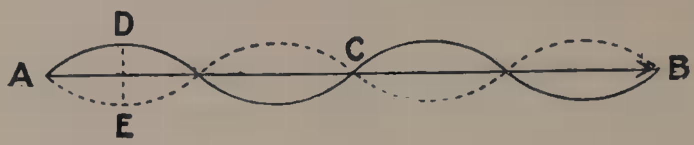

Fig. 1.

vibration, or distance traversed by the vibrating particles in passing from one extreme position to the opposite.

If now another ray of light of the same periodicity and the same phase of vibration start from a point a whole wave length in front of the first, one will intensify the other and we shall get more light; in other words, the ether particles acquire a greater amplitude. (Fig 2 (a).)

Fig. 2 (a).

Fig. 2 (b).

Let, however, the second ray (in opposite phase) start from a point half a wave length in front of the first, then one will neutralize the other, owing to the crests of one system being opposed to the troughs of the other and interference would result and consequently absence of light. (Fig. 2 (b).) It follows, therefore, that interference will occur when one system differs from another by an odd number of semi-undulations the same as holds good in the case of sound waves.

Zenker's theory: Stationary or stagnant waves.

A wave is said to be stationary when its form changes alternately from that of a crest to that of a hollow, but does not to the eye exhibit any progressive movement. Waves of this nature can readily be produced by the superposition of direct and reflected waves on a stretched cord. For this purpose we may make use of a long vulcanized rubber tube filled with sand having one end firmly

fixed at a convenient height. If the free end be quickly shaken a wave is produced which travels along the tube to the end and is there reflected and returns to the hand. By carefully timing the impulses given to the tube by the hand, a series of waves of the same length may be made to follow each other regularly, but the length of each half wave must be an aliquot part of that of the tube, such as ½, ¼, etc. When the tube vibrates as a whole, the length of the wave generated will be equal to twice that of the tube, because the wave is continually reflected at one fixed end and at the hand. To produce a wave on the tube which shall be equal in length to that of the tube itself it is necessary to shake the tube as fast again as when required to make it vibrate in the ordinary way. The effect of causing two half wave lengths exactly to extend along the tube is, that the direct and reflected waves will completely interfere with one another at the middle point along the tube. For as the direct wave leaves the hand a reflected wave from the fixed or opposite end will be traveling forward in opposite phase, and the consequence is that corresponding points in the two waves meet in opposite phase at the middle of the tube at the same moment, and as the vibrations would be equal in each direction the one would neutralize the other, and there would be no movement, as shown by the direction of the small arrows in Fig. 3.

Fig. 3.

The appearance of the tube to the eye is that of its two halves vibrating independently of each other, the middle point being at rest. The point where there is no perceptible motion is known as a node and the vibrating parts ventral segments.

It will now be self-evident that where we get no movement or no light, no chemical action can take place, while between these parts or at the position of the ventral segments we should have chemical action, and therefore deposit upon development, consequently we should have a series of layers or particles of silver separated by alternate blank spaces, and so obtain a record within the film of the different vibrations.

We are now in a position to follow the reasoning that has been adduced to account for the production of these photographs in colors and to understand the manner in which theoretical knowledge has been turned to practical account.

In a photograph taken in the ordinary way the deposit after development is present in the film as a continuous one, but in order to fulfil the conditions necessary in the subject under consideration it is essential that this continuity be broken up so as to produce

points of interference. We have seen that this can be brought about by the superposition of direct and reflected waves, and in taking these photographs a metallic mirror in the shape of mercury is in contact with the sensitive surface during the exposure in the camera, and this mirror is for the purpose of reflecting the incident light back upon itself, and so giving rise to interference within the film, with the result that, although vibration takes place, the effects of propagation are stopped, and instead of having propagated waves we get stationary waves, which rise and fall each in its own place, and so leave a record of their own forms, the largest movement leaving the strongest impression, and where there is no movement no impression would be left. So that there is formed a series of planes parallel with the surface of the mirror in which the light is alternately at a maximum and a minimum intensity. On development of such a plate we should have a series of strata corresponding to these maxima and minima, in which the deposit is alternately present and absent.

On viewing photographs taken under these conditions by means of white light falling upon them at a certain angle, the deposit in the film gives rise to interference, with the result that the constituents of white light which were active in forming the image are reflected to the eye of the observer.

To more clearly understand the subject let us consider for a moment the doctrine of color. Color is not an inherent quality in a body. It arises from the treatment on the part of the body of the incident light which falls upon it. Color is due to the extinction of some of the constituents of the white light within the body, the remainder which return to the eye imparting to the body the color which it appears.

In a soap film we have an excellent example of the manner in which interference colors are produced. Its thickness is found to be comparable to a wave of light, and, as it gradually thins by gravity, part of the film becomes of a thickness that the reflection from the back surface is half a wave length behind that reflected from the front, and one of the constituents of the white light would be destroyed at such place, and the color seen by the eye would be the result of the remaining components of white light.

Comparing this with our interference color photographs, supposing the blue constituent of white light to undergo reflection within the film at points situate half the wave length of the blue behind one another, the blue would be annihilated at these places and the remainder which would reach the eye would be the components of white less the blue. We have, therefore, a demonstration that the colors reflected from the film are not caused by any conversion of white light into colored light, but by the abstraction "due to interference" of certain colors from the components of white light.

The various hues of color can also be explained on the theory of partial interference only having taken place in parts: Thus

crimson and purple are the result of a mixture of red and blue, and the less the proportion of blue present the more will the red be felt, so that we should have tints ranging from purple to crimson, according to the proportions in which they are mixed.

That moisture also plays an important part in the rendering of these heliochromes is evident from the change in color produced by exposure to air. The writer has an example in which a certain part of the image is of a golden yellow, but on leaving it exposed to the air it assumes a coppery hue. The probable explanation is that the film takes up moisture when the distance apart of the laminæ becomes greater and reflects light of a greater wave length so that more red is felt. That such is the case appears to be borne out by the fact that on warming the film the image again appears of a golden yellow color, and if the heating be carried too far it becomes of a greenish-yellow.

In experimenting with this process, among several peculiarities noticed was one in particular which appeared to be directly connected with the successful rendering of the colors, and as it suggests the possibility (at least) of another explanation to account for the production of these heliochromes, we feel justified in advancing it, more especially as the same thing has already been suggested by Ives.*

In a large number of photographs by this process it rarely happens that the colors are seen the same from either side, and indeed with some of the writer's most successful results no colors whatever were visible from the glass side. Now, it would appear that, if the colors are simply due to interference of light reflected from deposited silver in a series of planes, the colors should be seen from either side, although it has been stated by Dr. Neuhauss** that these heliochromes are of two kinds—one in which the colors can be seen from either side, the other from the film side only. Another peculiarity of these heliochromes is that when viewed by ordinary reflection they resemble a positive, although the image is negative by transmitted light.

The conclusions to be drawn from this appear to indicate that these heliochromes can be produced by means of a single interference film of varying thickness backed up by different amounts of deposited silver. And that this interference film is the result of partial reversal brought about by the prolonged exposure in the camera.

Against this hypothesis, however, must be placed the recent experiments of Dr. Neuhauss** in which he states that having prepared sections and taken photomicrographs of them he found Zenker's thin laminæ were actually present, and that the distance of the laminæ represented in the photomicrographs corresponded exactly with the calculated distance of Zenker's laminæ for the particular region of

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* British Journal of Photography, December 15th, 1893.

** Eder's Jahrbuch, page 186, 1895.

the spectrum taken. This, then, would appear to be conclusive proof of the correctness of Lippmann's theory. Still, although there appears to be little doubt that the colors are due to interference, the conflicting nature of the results that are often obtained tend to show that they are not in harmony with the theory as originally put forth, and that some further explanation is necessary.

Having now given the theory as explained by Lippmann to account for the production of these heliochromes, together with our own observations in experimenting, we will proceed to describe in detail the practical working of the process.

Apparatus.

The only piece of apparatus required beyond that which every photographer already possesses is the special dark slide containing the mercury chamber. An illustration of the slide is shown at Fig. 4 open. In appearance it resembles the ordinary book form type, with the exception that in the place usually occupied by the second shutter is a fixture that forms the back of the mercury chamber (B).

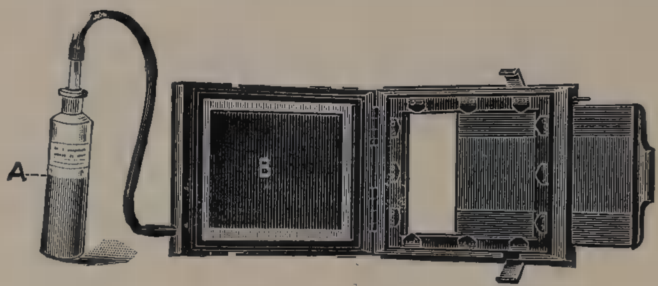

Fig. 4.

To use this apparatus the sensitive plate with its film side downwards is placed in this half of the slide resting upon a narrow rabbet of chamois leather. Twelve steel springs keep the plate firmly pressed against the leather and so prevent leakage of the mercury. The bottle (A) containing the mercury is, when everything is ready, held in such a position as will allow of the contents flowing down the rubber tube and into the space formed between the film and back of slide. It will be seen that the inlet is at the bottom of the slide so that the mercury on entering will rise in an uninterrupted wave over the surface of the film, but should any stoppage occur markings on the finished picture will be the inevitable result.

The mercury is prevented from returning by having a metal clip on the rubber tube or keeping the bottle above the level of that in the slide. A small valve (not shown in illustration) allows the displaced air to escape and an indicator shows when the slide is full.

As the use of the mercury is to form a perfect reflecting surface in contact with the film during its exposure in the camera, it is neces-

sary that it should be kept bright and clean. Having a decided objection to any chemical treatment, the writer "using pure mercury" has always resorted to running it through a paper cone "having a small orifice at its apex" or a small separating funnel; and finds this method to be satisfactory.

Lenses.

From the extreme slowness of the emulsion used in this process it becomes very necessary to employ lenses transmitting a large amount of light and capable of working well with a large aperture and having the shortest focus possible, and any of those which fulfil these conditions appear to answer in practice. Lippmann and others have mentioned the following as being suitable: Anastigmat Zeiss, 6.3; double anastigmat Goerz, 7.7; and also Voigtländer's Collinear, 6.3. And the writer has used a Ross rapid symmetrical and also a Petzval type of portrait lens of 6 inches equivalent focus, employing the full aperture in each case, and has obtained excellent results, the images covering a surface on the quarter plate of about two inches square.

Preparation of Emulsion.

When we come to consider that the colors of these photographs are said to be the result of the reflection from the different laminæ or strata within the film of the particular constituents of the white light which were active in forming them, and that the narrowest of these strata is not more than half the length of the shortest wave visible to our eyes, it is evident that the sensitive film must be of the finest possible nature, with an entire absence of any visible granularity. In fact, the film must be a transparent one.

In order to fulfil this condition Lippmann first of all used the albumen process as being one lending itself more particularly to the preparation of emulsions free from any visible grain.

In 1892 Messrs. Lumière, of Lyons, showed results which were greatly superior in brilliancy and beauty of coloring, and which had been produced upon gelatino-bromide plates, prepared by a formula which they published in 1893.

The method adopted in Lumière's process to ensure the sensitive salt being in the finest possible state of division consists in mixing the silver nitrate and potassium bromide in water containing the gelatine, and of employing a weak solution of these, and also keeping the temperature as low as possible during the process of mixing.

Under these conditions an emulsion is formed which is remarkable in appearance, being almost perfectly transparent, and plates coated with it at most only show the faintest opalescence.

By this modification one of the greatest drawbacks to the successful working of the process with gelatine plates was removed and a

means placed at our disposal which in careful hands is capable of yielding good results.

We now give the formulæ for the preparation of the emulsion as recommended by their respective authors:

Lumière's formula.

A

Water (distilled) ....400 c.c. or 14 oz.
Gelatine ....20 grams or 308.6 grains.

B

Water (distilled) ....25 c.c. or 7 drachms.
Potassium bromide ....3.5 grams or 54 grains

C

Water (distilled) ....25 c.c. or 7 drachms
Silver nitrate (recrystallized) ....5 grams or 77.15 grains

The gelatine is placed to swell in the 400 c.c. of water, the silver nitrate and potassium bromide are each dissolved in 25 c.c. of water, all three are then heated on a water bath to a temperature of 35° Centigrade or 95° Fahrenheit. The gelatine being dissolved, the solution is divided into two parts, to one of which is added B, to the other C. The two solutions are then mixed by pouring the one containing the silver nitrate into that of the potassium bromide, stirring well the while. If the operation has been carefully performed there will now result an emulsion of silver bromide in gelatine, which is transparent and of a golden color.

A modification of the above method by which a greater degree of sensitiveness is obtained (but at the risk of red fog) consists in dissolving the silver nitrate in the water in which the gelatine is swelled, thus:

A

Water (distilled) ....200 c.c. or 7 oz.
Gelatine............................10 grams or 154.3 grains
Potassium bromide.................... 3.5 " " 54 "

B

Water (distilled) ....200 c.c. or 7 oz.
Gelatine............................10 grams or 154.3 grains
Silver nitrate (recrystallized).......... 5 " " 77.15 "

The operations with regard to mixing, temperature, etc., are the same as before.

The writer, as the result of a number of experiments, was led to adopt the following formula:

A

Water (distilled)	225 c.c. or 7 oz. 7 drachms
Gelatine (Nelson's No. 1).............	5 grams or 77.15 grains
Potassium bromide	2.1 " " 32.4 "

B

Water (distilled)	225 c.c. or 7 oz. 7 drachms
Gelatine (Nelson's No. 1).............	5 grams or 77.15 grains
Silver nitrate (recrystallized)	3 " " 46.29 "

Each having been brought to a temperature of 35° C. (95° F.), B is added to A with continual stirring.

Valenta's formula.

A

Water (distilled)	300 c.c. or 10½ oz.
Gelatine	10 grams or 154.3 grains
Silver nitrate	6 " " 92.58 "

B

Water (distilled)	300 c.c. or 10½ oz.
Gelatine	20 grams or 308.6 grains
Potassium bromide	5 " " 77.15 "

Each having been brought to 35° C. (95° F.), A is added to B gradually.

With the Lippmann process it is a *sine qua non* that the plates should be orthochromatic.

To this end 2 c.c. or about ½ drachm of the following is stirred into every 100 c.c. or 3½ oz. of emulsion.

Alcoholic solution of cyanine (1 to 500).....	4 c.c. or 1 drachm
" " " erythrosine (1 to 500)...	2 c.c or ½ "

The emulsion is then filtered through glass wool, pure cotton wool, hemp, or No. 1 Swedish filter paper, and the plates coated without delay. The glasses, which should be patent plate and which must have been made chemically clean by immersing them in nitric acid and water (1 to 10), washing and rubbing over them a weak solution of caustic soda or potash and a little methylated spirit, and after washing under the tap, rinsing in distilled water, and setting up to dry on clean blotting paper, are warmed, and the filtered emulsion poured over in the manner of collodion, the excess being returned to the filter.

The coated plate is now placed on a levelled glass or marble slab

to set; when set each plate is immersed for a minute in alcohol and washed for fifteen minutes in water, drained, and dried.

Plates that have been prepared with the plain emulsion may also be rendered color sensitive by dipping, although perhaps the results are not quite so good when the emulsion itself has been treated.

To proceed in this manner immerse the plates for two minutes in the following:

Water (distilled) ....100 c.c. or 3½ oz.
Alcoholic solution of cyanine (1 to 500)........4 c.c. or 1 drachm

Or a similar solution of erythrosine, or a mixture of the two.

The cyanine confers a maximum sensitiveness from D to C, erythrosine from E to D of the spectrum.

Quite recently the following method of preparation of the emulsion has been given by Professor Lippmann, and differs somewhat from the foregoing:

Lippmann's formula.

Water (distilled)	100 c.c.	or	3½ oz.
Gelatine	4 grams	or	61.72 grains
Potassium bromide	.53 "	"	8.1 "

For orthochromatizing add about 6 c.c. or 1½ drachms of an alcoholic solution of cyanine (1 to 500) and 3 c.c. or 45 minims of an alcoholic solution of chinoline red (1 to 500).

Having mixed the above at a temperature of 35° C. (95° F.) and in red light add .75 gram or 11.5 grains of dry powdered silver nitrate, and stir until dissolved. Filter through glass wool and coat plates as before. Allow the emulsion to set, place each plate in alcohol, then wash for half an hour, drain and dry. The plates in this condition would keep a long time.

Owing to the disadvantages attending the washing of the plates themselves, any method which would obviate this, and at the same time allow of the necessary fineness of grain being obtained, would be a distinct gain. Valenta with his formula recommends pouring the emulsion in a fine stream into 1 litre (35.22 oz.) of alcohol 90 per cent., cutting up and washing for a short time in running water, re-dissolving and coating plates as usual. Although a considerable amount of success attended a trial of this method, the plates could not be said to be as transparent as those prepared by the original plan.

It is usually recommended to whirl the plates after coating; experiment, however, shows that this is not only unnecessary, but is harmful, as not only are the colors less brilliant, but the general sensitiveness of the plate is reduced by so doing.

Increasing sensitiveness of plates.

Several methods having been given by which the general sensitiveness of these plates may be increased, the following, by Professor Lippmann, is perhaps one of the best:

Lippmann's method.

Alcohol (absolute)	100 c.c. or 3½ oz.
Silver nitrate	.5 gram or 7.7 grains
Acetic acid (glacial)	.5 c.c. or 7 minims

The dried plates are immersed in this for about a minute, whirled, and again dried, and must be used as soon after as possible, as they will not keep.

Lumière's method.

Water (distilled)	200 c.c. or 7 oz.
Silver nitrate	1 gram or 15.43 grains
Acetic acid (glacial)	1 c.c. or 15 minims

The plates are immersed for two minutes in the above and dried.

To the same end Valenta recommends the addition of 1 gram (15.43 grains) of sodium sulphite to every 300 c.c. (10½ oz.) of emulsion and subsequent heating to 38° C. (100° F.) for a short time.

The writer, working in the same direction, but with the desire to take advantage of the use of silver eoside as a sensitizer for mixed

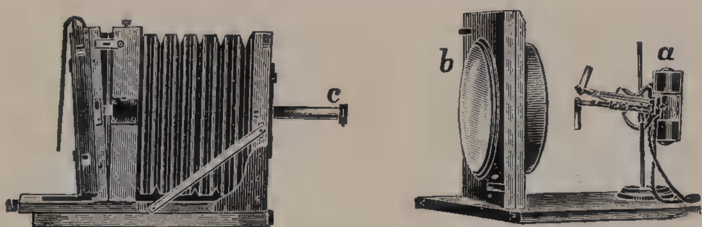

Fig. 5.

colors, prepared this substance in the form of a powder and added .2 gram (3 grains) to 100 c.c. (3½ oz.) of emulsion. This method was found to greatly increase the general sensitiveness, plates exposed behind a Warnerke sensitometer for five minutes to a sixteen candle-power incandescent lamp showing the number nineteen distinctly on development, against the number nine with the same emulsion without the addition of the dye and silver compound. Further trials have confirmed this, as well as the excellence of the substance as a color sensitizer.

Exposure of the plate.

There is no doubt that the most suitable object from a theoretical point on which to experiment would be the spectrum, and at Fig. 5

is shown a photograph of the apparatus as arranged for this purpose. A is a small arc lamp, B a condensing lens placed so that the light is focussed on to the slit of the spectroscope, C (a direct vision one) attached to a camera.

The writer, however, for certain reasons, preferred experimenting on objects by means of reflected light, and for this purpose made up a test subject composed of brightly colored ribbons arranged in form of a star.

It was found that, working in the open air and illuminating the object by sunlight and employing a portrait lens of six inches focus with full aperture, "the size of image formed being two-thirds that of the original," the exposure required to produce good results (using plates that had not been treated with a chemical sensitizer to increase their sensitiveness) varied from fifteen to twenty minutes.

One thing most noticeable was the importance of the objects being brilliantly illuminated, and although there is a certain latitude in the exposure it appears to be much less than in ordinary cases.

Exposure meters seem of very little use, and careful experiments, noting all the conditions under which the photographs are taken, appear to be the only safe guide in practice. However, in taking a sunlit landscape, including moderately close objects, and using a Zeiss 6.3 lens and employing the most sensitive plates, the exposure would be about two minutes. Exposures made with and without light filters to exclude the ultra-violet rays produced results which were not distinguishable one from another; therefore, the use of a screen for this purpose would appear to be unnecessary. What is more particularly required seems to be a plate which is equally sensitive throughout the entire spectrum rather than one whose sensitiveness is greatest to the most luminous portion.

Before placing the prepared plate in the dark slide it must be carefully dusted with a soft brush, and when in position the outer surface cleaned from any deposit there may be upon it. The mercury is now introduced slowly, but without any stoppage, and when this can be performed in the dark room it is advisable to draw out the shutter and watch the inflow of it, and if any air bells form on a part of the plate on which the image will fall the whole operation must be repeated until they are absent.

On removing the exposed plate from the slide, a broad soft camel hair brush must be lightly passed over it several times in order to remove any adhering mercury on the film and which would result in streaks and markings of a metallic lustre on the finished picture. Dr. Neuhauss* recommends dipping the brush in alcohol as being more effective for this purpose. The plate is now ready for development.

Developing.

Owing to their extreme slowness, a large amount of light can be

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* Eder's Jahrbuch, 1898.

employed in the dark room with safety in the development of these plates. In our own practice a sixteen candle-power incandescent lamp covered with one thickness of Canary medium is used.

The developer may be any of those usually employed: Pyro, Amidol, Metol, Eikonogen, etc., although perhaps the best for the purpose is the Pyro-ammonia originally recommended by Lumière, thus:

Lumière's formula.

No. 1.

Pyrogallol	1 gram or 15.43 grains
Water (distilled)	100 c.c. or 3½ oz.

No. 2.

Potassium bromide	10 grams or 154.3 grains
Water	100 c.c. or 3½ oz.

No. 3.

Ammonia .960 at 18 C., practically a 10 per cent. solution.

For use take:

No. 1	10 c.c.	or	2½ drachms
No. 2	15	"	3¾ "
No. 3	5	"	75 minims
Water	70	"	2½ oz.

Valenta's formula.

A.

Pyrogallol	4 grams or 61.72 grains
Water (distilled)	400 c.c. or 14 oz.
Nitric acid	6 drops

B.

Potassium bromide	10 grams or 154.3 grains
Water (distilled)	400 c.c. or 14 oz.
Ammonium sulphite	12 grams or 185.16 grains
Ammonia .91	14 c.c. or 3½ drachms

For use take two to three parts of B and one part of A and twelve to fourteen parts of water.

From recent experiments, either of the two following formulæ can be recommended as giving good results, and as that of the pyro is made from the ten per cent. solutions in every-day use it is perhaps more convenient:

Pyro developer.

Pyrogallol (10 per cent. solution)	5 minims
Potassium bromide (10 per cent. solution)	1 drachm
Water	1 oz.
Ammonia (10 per cent. solution)	10 minims

Amidol developer.

Amidol	2.5 grains
Sodium sulphite	36 "
Potassium bromide	2 "
Water	1 oz.

The development of these plates takes place rapidly and is usually complete in about one minute, but their behavior during the process is peculiar, and one soon gets to know by their appearance whether or not the exposure has been correct and that the colors will be visible on drying. At first nothing unusual is apparent, but a point is soon reached where there is distinct evidence of reversal "over the whole or part of the image," and it is at this stage where the greatest judgment on the part of the operator is required.

That this phenomenon must be present has been noticed with all the successful results, and in its absence, although the deposit forming the image may have been considerable, the colors have either been wanting entirely or very weak.

Further than this, it can only be said that development should be discontinued soon after this appearance is manifest and the image by transmitted light appearing as a reddish brown stain of good depth.

Plates whose sensitiveness has been increased by the use of silver nitrate have a great tendency to show surface fog if the development is forced in the slightest, but fixing in the cyanide solution will remove this; the best course, however, is to give sufficient exposure in order that development may be complete in about the time indicated.

Fixing.

After rinsing from the developer, the image may be fixed by means of either sodium thiosulphate (hypo) or potassium cyanide. Lippmann recommends hypo of the following strength:

Sodium thiosulphite (hypo)	150 grams or 4.6 oz.
Water	1000 c.c. or 35.22 oz.

The fixing takes place very rapidly.

MM. Lumière and Valenta recommend potassium cyanide of the following strength, and say that the colors are more brilliant when it is employed:

Potassium cyanide	5 grams or 77.1 grains
Water	100 c.c. or 3½ oz.

Owing to the great tendency of this to attack the finely divided silver composing the image, the plate must not be left in the solution longer than from ten to twenty seconds and then well washed in running water for half an hour.

On drying the colors will appear, but should they not be as brilliant as desired this may be increased by careful intensification, and Lippmann states that it seems to be more advantageous to develop little and intensify with mercury and amidol.

Intensifying.

To intensify a Lippmann photograph we proceed as in the case of an ordinary negative, only using a more dilute solution of mercuric chloride of about the following strength:

Mercuric chloride	2 grains
Potassium bromide	2 "
Water	1 oz.

If the plate has already been dried it must be placed for about five minutes in clean water and then immersed in the above solution until the film is bleached; it is then well rinsed, and an ordinary amidol developer is flowed over until the film is blackened through, or a solution of sodium sulphite of the following strength may be employed:

Sodium sulphite	1 oz.
Water	10 "

The plate is then washed and again dried.

The writer having been very successful with physical intensification employs the following formula for the purpose:

Pyrogallol	2 grains
Citric acid	3 "
Water (distilled)	1 oz.

To which is added immediately before use a few drops of a ten-grain solution of silver nitrate. This solution is flowed over the plate held in the hand and the result carefully watched, and when the increase of density, which must not be great, is judged to be sufficient, the plate is washed, and placed for a few seconds in the cyanide fixing solution, well washed and again dried. By this treatment, if the action has not been allowed to proceed too far, the colors will appear much brighter and unaltered in tint.

If success has attended the various operations it now only remains to examine the photograph as a Daguerreotype is viewed, when the colors of the object photographed will be plainly visible. That is to say, the eye must be in the direction of the regularly reflected ray; if you look from another point you see only a colorless image.

A much greater degree of brilliancy and transparency is imparted to these heliochromes and at the same time disturbing surface reflections eliminated by cementing a shallow prism to them by means of Canada balsam. A piece of black glass or a coating of black varnish should also be applied to the back of the plate and they are then complete.

In the absence of daylight for viewing these heliochromes, they should be seen by light transmitted through a sheet of opal glass in front of a lamp, or that reflected from an opal shade. In order, however, to show them to best advantage, they should be thrown by opaque projection on to a screen, using a megascope or aphengescope lantern. But in this case it becomes necessary to employ a powerful electric arc light to project them with satisfactory brilliancy even up to a small size.

Omission must not be made of the recent experiment of Dr. Neuhauss* the results of which show that heliochromes of the spectrum are much more easily obtained on albumen plates than on gelatine, and that it is only necessary to coat a glass plate with pure albumen and when dry sensitize in the silver nitrate bath, and then treat with the color sensitizers.

After exposure the plates are developed with pyro-ammonium carbonate and potassium bromide, the development taking place as slowly as possible. Unfortunately, however, these plates do not appear to be suitable to the reproduction of mixed colors.

Experiments also are not wanting to show that these heliochromes can be produced without the use of silver salts at all, Lippmann having shown results obtained with bichromated gelatine, and St. Florent is said to have been successful with ferric chloride and gelatine.

In conclusion, we can only say that whatever future developments there may be, the process itself is a most fascinating one, and it is hoped that the information here given may induce others to experiment with it, and to those already engaged the matter may be found useful for reference.

* Eder's Jahrbuch, 1898.

INDEX.

Abney, 37, 40, 45, 46, 47, 48, 63, 79, 89, 90, 94, 96, 144, 145, 172, 207.
Abney, on Plates, 48.
Abney's Color Sensitometer, 46, 145.
Absorption, 99.
Absorption, Selective, 101.
Acetylene, 93.
Adjustment of Lens and Prism, 85.
Amidol Developer, 224.
Angle of Plate, Effect of, 83.
Angles of Ruled Screens, 202.
Apparatus for Lippmann Process, 216.
Apparatus, Visual, 112.
Arrangement, Illuminating, 79.
Arrangement, General, 79.

Barnard, 48.
Beams of Colored Light, Separation of, 96.
Beams of White Light, Separation of, 96.
Beauregard, Testud de, 5, 15, 16.
Becquerel, 5, 9, 11, 18, 27.
Bennetto, M., 7, 192.
Bichromate, Gum, 52.
Boys, C. V., 16.
Brewerton, 52.
Brewster's Optics, 4.
Brightness, 106.

Camera, 182, 184.
Cell, Mercury, 33.
Cells, Forms of, 154.
Chromo-sensitive Surface, Ideal, 11, 12, 13.
Chromodialytique, Polyfolium, 7.
Church, Prof., 100, 104.
Clerk-Maxwell, 6, 39, 67, 114, 115.
Collen, H., 6, 40.
Color, 94, 104, 107.
Color Blindness, 107.
Color Diffraction, 99.
Color Filters, 150, 157, 164, 200.
Color in Nature, 99.
Color Mixture Curves, 114, 118.
Color Nomenclature, 112.
Color Records, 141, 203.
Color Record Negatives, 182.
Color Screens, 147.
Color Sensations, 39, 118, 205.
Color Sensation Theory, Young-Helmholtz, 45.
Color-sensitive Plates, 143.
Color Sensitometer, Abney's, 46, 145.
Color, Sources of, 99.
Color Constants, 105, 136.
Colored Lights, Influence of, 95.
Colored Screens, 51.
Colors, Complementary, 44, 97.
Colors, Interference, 99.
Colors, Minus, 97.
Colors of Natural Objects, 103.
Colors, Primary, 111.
Colors, Printing, 47.
Colors, Reproduction, 111, 124, 127, 129.
Colors, Spectrum, 131.
Colors, Standard, 111.
Colors, "Taking," 124.
Collimator, 80, 84.
Collodion, Use of, 159.
Collotype Method, 200.
Complementary Colors, 44, 97.
Composition of Pigments, 132.
Constituent Beams of White Light, Separation of, 71.
Couleurs en Photographie, Les, 5, 40, 49.
Couleurs en Photographie: Solution du Problème, 5.
Cros, Charles, 6, 19, 40.
Curves, Color-sensation, 39, 114.

Daguerre, 4.
Dark Room Lights, 169, 173.
Departures from Theoretical Conditions, 137.
Developers, 172, 224.
Developing, 222.
Development, Correct, 170.
Development, Influence of, 169, 170.
Deviation, Minimum, 83, 85.
Dialytic System, 7.
Diffraction Color, 99.
Diffraction Gratings, 195.
Diffraction, Heliochromy, 8.
Diffraction Pictures, 198.
Diffraction Process, 193.
Direct Vision Prisms, 92.
Direct Vision, 90.
Direct Vision Spectroscopes, 91.
Dispersion, 75.
Dispersion by Parallel Plate, 75.

Dispersion by Prism, 76.
Dispersion at Surface, 75.
Displacement of Ink-Spot, 73.
Dittmar, 15, 16.
Dominant Hues, 97, 121.
Dublin Royal Society, 49.
Du Hauron, 191. See "Hauron."
Dyes, 173.

Effect of Angle of Plate, 83.
Electric Light, Arc, 93.
Electric Light, Incandescent, 93.
Emulsion and Developer, Formula for, 33.
Emulsion, Preparation of, 217.
Exposure of Plate, 221.
Exposures, Relative, 166.

Fidelity of Reproduction, 146.
Films, Superimposing, 43.
Fish Glue, 204.
Filters, 147, 152, 173.
Filters, Color, 159, 164, 200.
Fixing, 224.
Fluorescence, 100.
Focal Length, 82.
Focussing, 85.
Formula for Emulsion and Developer, 33.
Formula for Filters, 159.
Formula, Lippmann's, 33, 220.
Formula, Lumière's, 218, 223.
Formula, Valenta's, 219, 223.
Fraunhofer Lines, 87, 88.

Gaslight, Incandescent, 93.
Gaslight, Ordinary, 93.
Gelatine, Use of, 158.
Genesis of Three-Color Photography, 67.
Glass for Filters, 152.
Glue, 204.
Goethe, 3.
Gowenlock, 48.
"Graphed" Scale of Spectroscope, 87.
Grating, Prism, 92.
Gratings, 91.
Gratings, Diffraction, 195.
Gum Bichromate, 52.

Hauron, Louis Ducos du, 5, 6, 7, 16, 27, 37, 40, 41, 43, 45, 48, 49, 191.
Heliochrome, Viewing the Lippmann, 35.
Heliochrome, Projecting the Lippmann, 35.
Heliochromes, Interference, 33.
Heliochromes, Lippmann, Reproduction of, 36.
Heliochromic Triad, Individual Prints for, 52.
Heliochromy, 8, 22, 25, 37, 40, 52, 211.
Heliostat, 79.
Helmholtz, 67, 114.
Herschel, Sir John, 4, 13, 15.
Hues, 97, 107, 109, 111, 121, 131.
Hunt, 5, 13.

Ideal Chromo-sensitive Surface, 11, 12, 13.
Illuminating Arrangements, 79.
Illumination, Artificial, 179.
Illumination, Brightness of, 108.
Image, Size of, 82, 108.
Images, Overlapping, 78.
Images of Slit, 79.
Imperial State Paper Office, St. Petersburg, 48.
Impurity, 76.
Incandescent Gaslight, 93.
Incandescent Electric Light, 93.
Individual Prints, Heliochromic Triad, 52.
Influence of Colored Lights, 95, 148.
Inks, Printing, 200, 203.
Ink-Spot, Displacement of, 73.
Intensifying, 225.
Interference Colors, 99.
Interference Effects, 27.
Interference Heliochromes, 33.
Interference Heliochromy, 22, 25, 311.
Ives, Fred E., 6, 37, 38, 41, 42, 43, 63, 64, 68, 172, 176, 191.

Joly, 5, 6, 37, 49, 69, 185.
Jourdain, P. E. B., 8.

Kopp, 19.
Kromograms, 177, 178.
Kromskop, 42, 44, 68, 69, 162, 175, 176.
Kromskop, Lantern, 180.
Kromskop, Monocular, 180.
Kromskop Negatives, Development of, 185.
Kromskop, Principles of Working, 179.
Kromskop, Stereoscopic, 193.

Laminated Structure, 9, 22.
Lamplight, 93.
Lantern Kromskop, The, 180, 181.
Lantern for Triple Color, 180.
Lea, M. Carey, 6, 13, 14, 15.
Length of Spectrum, 82.
Lens, Adjustment of, 85.
Lenses, 81, 217.

Lenses, Optical Requirements of, 152.
Lenses and Slit, Use of, 76.
Light and Color, Study of, 71.
Lights, Colored, Influence of, 95.
Lights, Dark-Room, 173.
Light, Source of, 79, 93.
Lights, Percentage Composition of, 93.
Light, Wave Length of, 26.
Limelight, 93.
Lines, Fraunhofer, 87.
Lippmann, Gabriel, 4, 6, 9, 26, 28, 36.
Lippmann Heliochromes, 35, 36.
Lippmann Plate, 34.
Lippmann Process, 28, 193, 211, 221.
Lippmann's Formula, 33, 220.
Lithographic Method, 200.
Lottermoser, 14.
Lumière, 31, 35, 191.
Lumière's Formula, 189, 218, 221, 223.
Lumière Panchromatic Plates, 51.
Luminosity, 124.
Lumley, 48.

Maxwell's Color Mixture Curves, 112.
Mayer, 14, 79.
Measurement, 106.
Mercury Cell, 33.
Mercury, Reflecting Mirror of, 32.
Minimum Deviation, 83, 85.
Minus Colors, 97.
Modern Chromatics, 104.
Modifications of Spectroscope, 90.
Monocular Kromskop, 180.
Multiple Back, 183.
Mutual Transmission, 103.

Negatives, Color Record, 182.
Negatives, Screen, 203.
Neuhauss, 15, 28, 215, 222, 226.
Newton, 4, 24, 37.
Newton's Rings, 26, 32.
Niepce, J. Nicephore, 4.
Niepce, Second, 5.
Noack, Prof., 52.

One-Plate Process, 51.
Opalescence, 99.
Optical Contact, 137.
Optics, Brewster's, 4.
Ordinates, 115.
Orthochromatic Plates, 141.
Orthochromatism, 144.
Over-development, 170.
Overlapping Images, 78.
Overlapping Spectra, 77.

Parallel Plate, Refraction, 74.
Photochromoscope, 44.
Photochromy, Handbook of, 27.
Photographie en Couleurs, 40, 49.
Photography, 141.
Photogravure Method, 200.
Photospectroscope, 80.
Pictures, Diffraction, 198.
Pigment Prints, 43.
Pigmentary Effects, 27.
Pigments, Composition of, 132.
Plate, Exposure of, 221.
Plate, Failure of, 170.
Plate, Lippmann, 34.
Plates, Abney on, 48.
Plates, Backing the, 173.
Plates, Color-sensitive, 143.
Plates, Lumière Panchromatic, 51.
Plates, Sensitiveness of, 221.
Plates, Separate, 142.
Polarization, 99.
Polyfolium Chromodialytique, 7.
Positions of Slits, 109.
Positives, Triple Superposed, 188.
Prevention of Scattered Light, 86.
Primary Colors, 111.
Printing Colors, 47.
Printing Inks, 200.
Prints, Pigment, 43.
Prism, 80, 81, 82, 85, 92.
Prism Grating, 92.
Prism, Refraction through, 74.
Projection Lantern, 175.
Pure Spectrum, 78.

Quantitative Application, 131.

Rays, Ultra-Violet, 148.
Recombination, 96.
Reflecting Mirror of Mercury, 32.
Refraction, 72, 73, 74.
Relative Exposures, 166.
Reproduction Colors, 111, 127.
Reproduction, Fidelity of, 146.
Requirements in Spectroscope, 72.
Rings, Newton's, 26, 32.
Ritter, Herr, 3.
Rood, 104.
Ruled Screens, 202.
Rumford, 94.

Saint Florent, 16, 17, 18, 19.
Scaling, 87, 89.
Scattered Light, Prevention of, 86.
Screen Negatives, 203.
Screens, 207.
Screens, Colored, 51.
Screens, Ruled, 200.
Screen, Taking, 50, 51.
Screen, Viewing, 50, 51.
Seebeck, T. J., 3.

Seebeck Effect, 9.
Selective Absorption, 101.
Sensitometer, 144, 145.
Sensitometer, Abney's Color, 46.
Separate Plates, 142.
Separation of Beams of White Light, 71, 96.
Shepherd, Sanger, 190.
Simpson, G. Wharton, 17, 18.
Size of Image, 82, 108.
Skylight, 93.
Slit, The, 79, 84, 105, 109.
Slit, Use of Lenses and, 76.
Source of Light, 79, 93.
Sources of Color, 99.
Spectra, Overlapping, 77.
Spectroscopic Test, 161.
Spectroscope, Construction of, 80.
Spectroscope, "Graphed" Scale of, 87.
Spectroscope, Modifications of, 90.
Spectroscope, Requirements in, 72.
Spectroscopes, Direct Vision, 91.
Spectrum Colors, 131.
Spectrum, Hues, 109.
Spectrum, Length of, 82.
Spectrum, Pure, 78.
Spectrum Reproduced, 136.
Spectrum Slits, 105.
Standard Colors, 111.
Stereoscope, 176.
Stereoscopic Kromograms, 178.
Stereoscopic Kromskop, 193.
St. Petersburg Imperial State Paper Office, 48.
Structure, Laminated, 22.
Study of Light and Color, 71.
Sunlight, 93.
Superimposing Films, 43.
Synthetic Heliochromy, 37.

Table of Wave Lengths, 88.
Table of Fraunhofer Lines, 88.
Taking Screen, 50, 51.
Test, Preliminary Spectroscopic, 161.
Theoretical Conditions, Departures from, 137.
Three-Color Heliochromy, 52, 142.
Three-Color Photography, 64, 68.
Three-Color Typographic Printing, 138, 200.
Tones, 170.
Transmission, 99, 103.
Transparencies, 185.
Transparencies, Three-Color, 190.
Trichromatic Heliochomy, 40.
Triple Color, Lantern for, 180.
Triple Slit, 89, 90.
Triple Superposed Positives, 188.
Turning Screens, Method of, 202.
Typographic Printing, 138, 200.

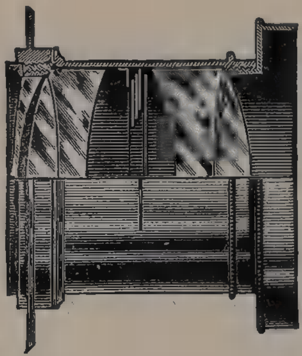
Ultra-Violet Rays, 148.
Under-development, 170.

Valenta's Formula, 219, 223.
Variations of Curves, 114.
Viewing Screen, 50, 51.
Vision, 90, 107.
Visual Apparatus, 112.
Vogel, Prof., 68.
Von Helmholtz, 114.

Wave-Length of Light, 26, 88, 107, 141.
Waves, Stationary, 212.
Weissenberger, 48.
White, Walter, 185.
Wiener, Herr Otto, 6, 9, 12, 13, 14, 15, 17, 27, 28, 36.
Wollaston, 4.
Wood, R. W., 8, 69, 193, 198.
Woodburytype Process, 192, 200.

Young, Dr. Thomas, 24, 39, 67, 114.
Young - Helmholtz Color - sensation Theory, 45, 205.

Zenker, Dr. Wilhelm, 6, 27, 28, 212.
Zenker-Lippmann, 6.



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Also TELEPHOTO . . . ATTACHMENTS for same.

THIS is a new universal Lens of more simple construction than Series I, consisting of 5 Lenses only. It is intended to be a **Lens suitable for every class of Photography, from Portraiture to Wide-Angle work, and is the quickest Stigmatic Lens made,** except the Dallmeyer Stigmatic Portrait Lenses, Series I, which work in $4 f/$. The smaller sized plates mentioned in these specifications are the size we should advise for general work with Lenses of the respective foci, since the use of a Lens of too short focus tends to the production of exaggerated perspective. At full aperture these lenses cover slightly larger plates than those given, and include an angle along the diagonal of the plates of about 85°.

Moreover, being perfectly free from spherical aberration, the full aperture of the Lens may be used in focusing, there being no fear of any alteration taking place in the focal length of the Lens, when changing the size of the stop, as is the case with many Lenses of the Wide-Angle type.

No.	Plate Covered at Full Aperture.	Largest Plate covered at	Diam. of Lens.	Eq. Focus.	Price with Iris Diaphragms.	Price and Focus of Suitable Telephoto Attachment in Brass.	
	f/6.	*f/16.*	In.	In.			
1	3¼ × 3¼	4¾ × 6½	.8	4.5	$38.00	2½ inch,	$30.00
2	3¼ × 4¼	5 × 8	.9	5.3	46.00	2½ "	30.00
3	4 × 5	6½ × 8½	1.1	6.4	54.00	3 "	30.00
4	4¾ × 6½	8 × 10	1.3	7.6	65.00	4 "	36.00
5	5 × 8	10 × 12	1.6	9	84.00	4 "	36.00
6	6½ × 8½	12 × 15	1.9	10.7	108.00	5 "	42.00
7	8 × 10	15 × 15	2.2	12.7	148.00	6 "	48.00
8	10 × 12	16 × 18	2.6	15.1	196.00	7 "	56.00
9	12 × 15	20 × 22	3.1	18	252.00	8 "	68.00

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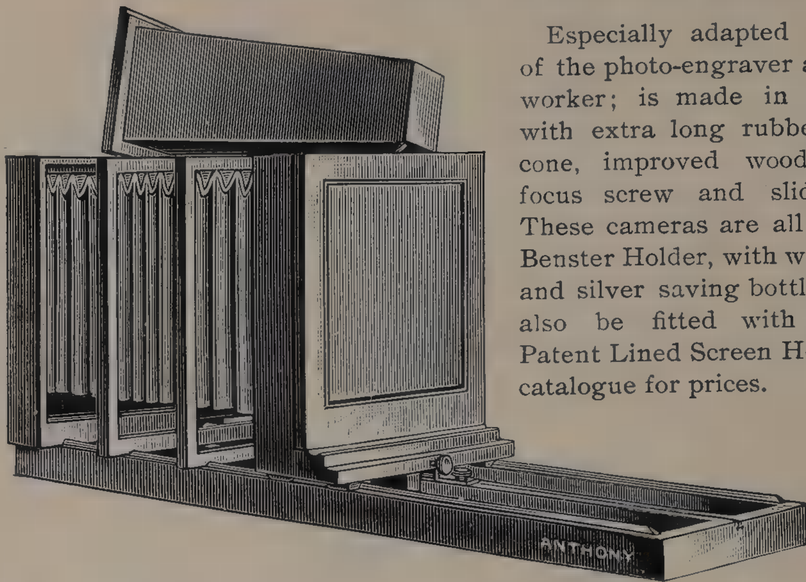

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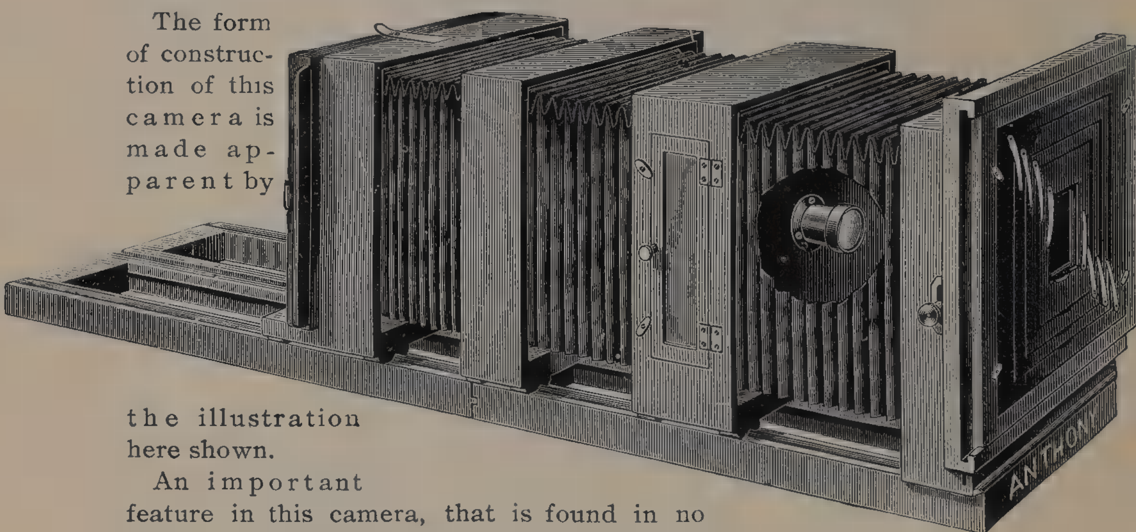

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An important feature in this camera, that is found in no other, is that the centre-board with lens can be used in the end of the camera, converting it at once into an extra long copying camera. This will be found very advantageous in enlarging small pictures by one operation.

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